GRAVITATIONAL-WAVE DETECTION

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Photo: Jerome Degallaix

PSR B1913+16 / the Proof

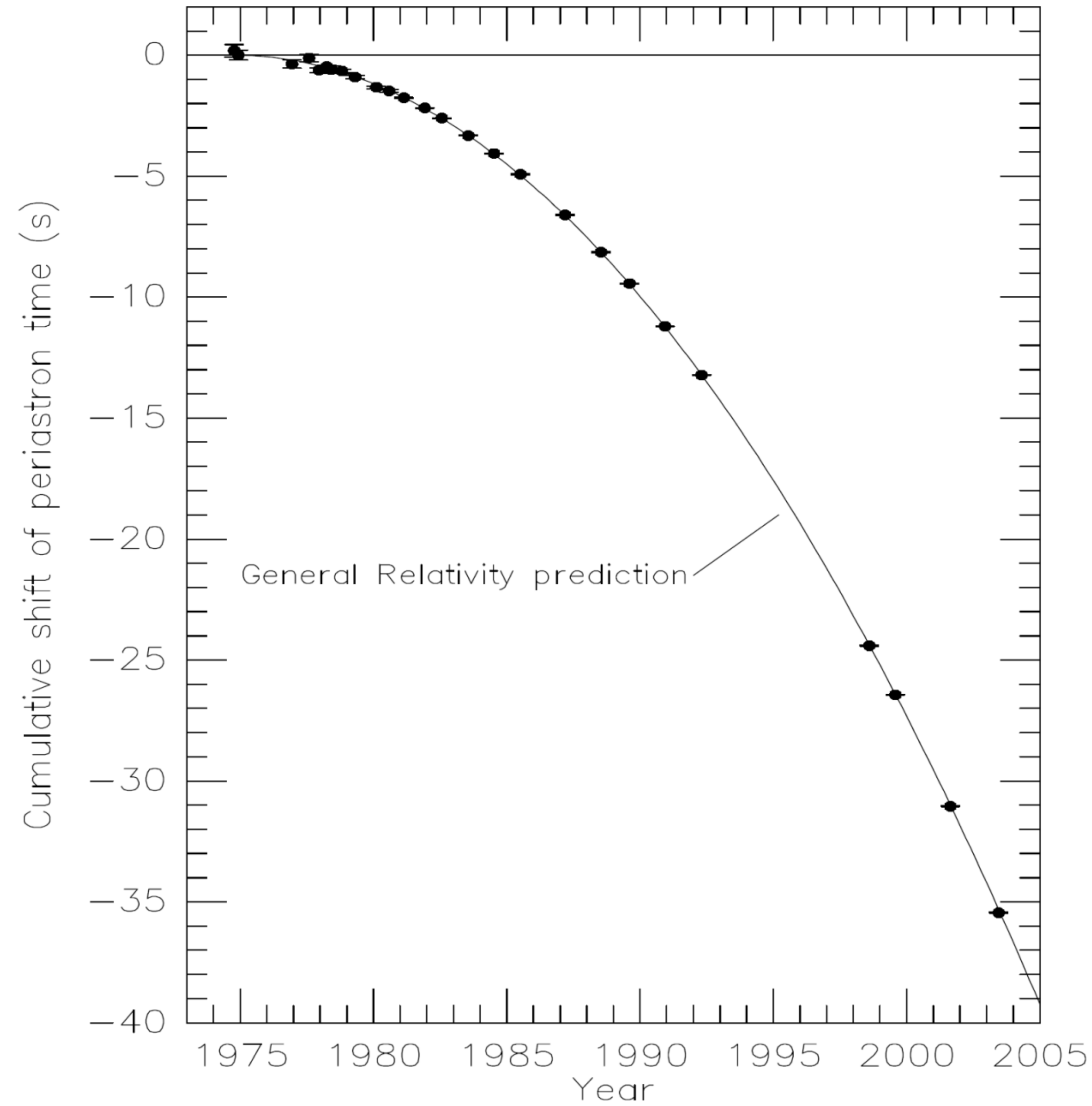
Russell A. Hulse
Joseph H. Taylor, Jr.
In 1974 discovered
the first pulsar
in a binary system
Period ~ 8h

Indirect detection of GWs

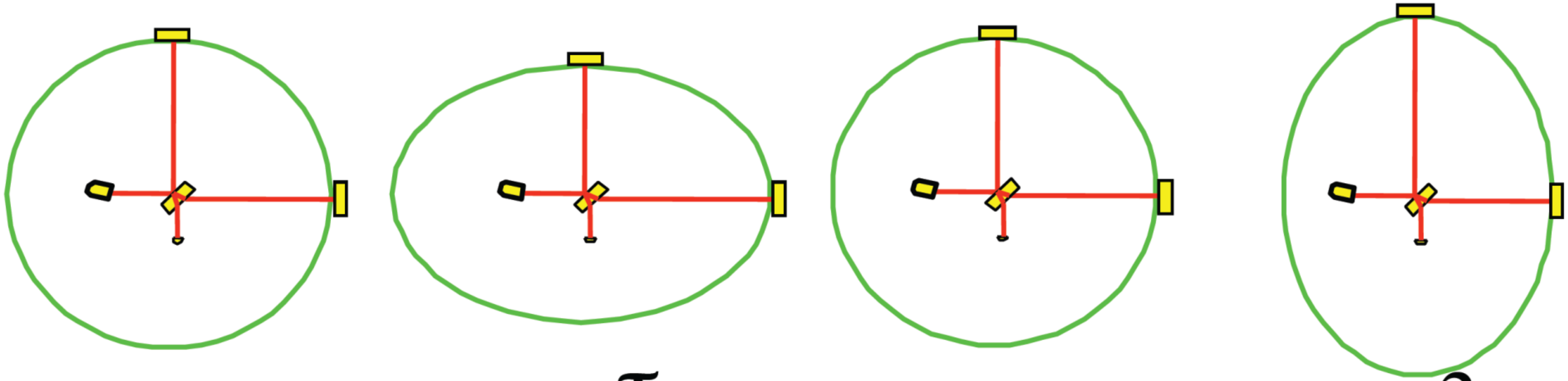
Nobel Price 1993

periastron advance is about 4.2 degrees per year

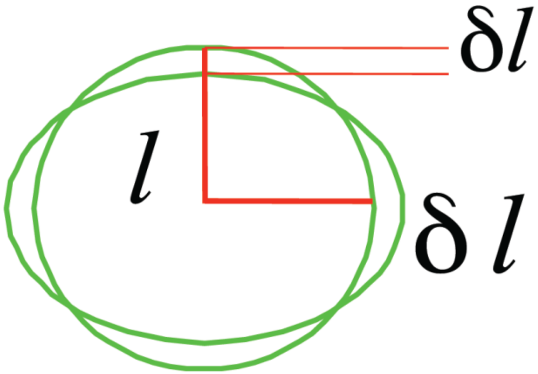
Δt_P [s] Periastron advance



The Effect of GWs



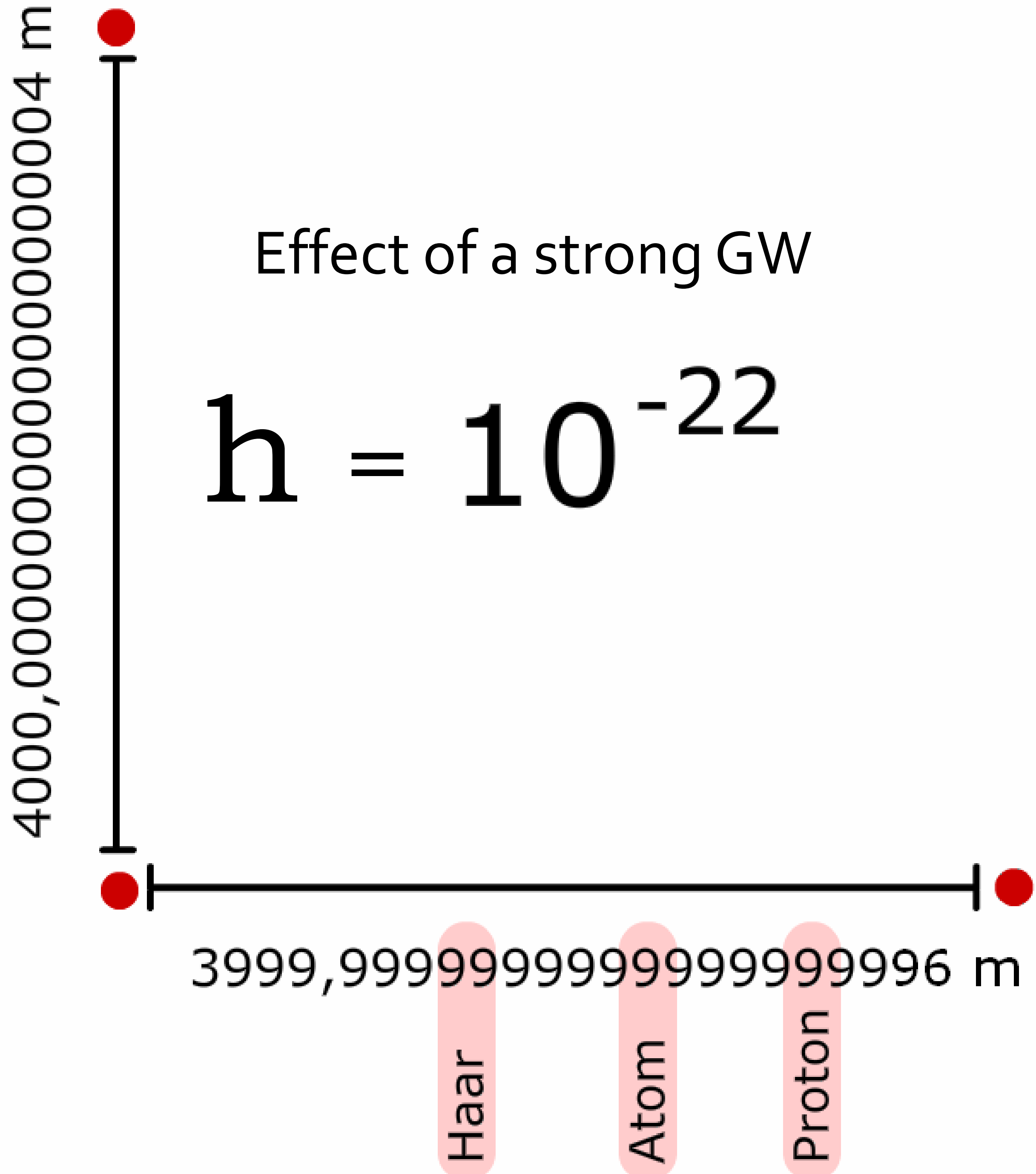
$t = 0$ $\quad t = \frac{\tau}{4}$ $\quad t = \frac{\tau}{2}$ $\quad t = \frac{3\tau}{4}$



$$\delta l = \frac{h}{2} l$$

For Typical Astronomical sources

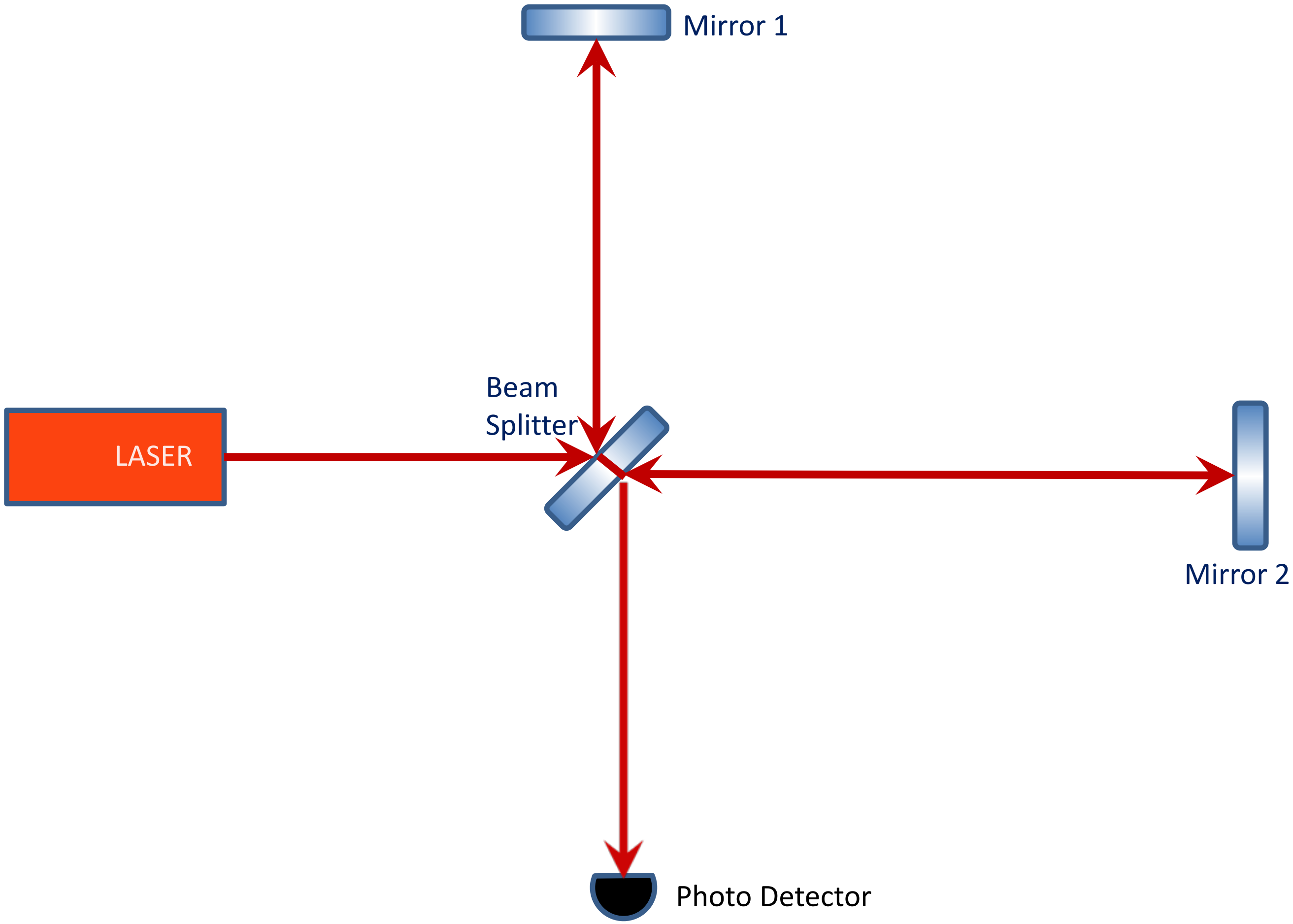
$$h = \frac{2\delta l}{l} \leq 10^{-22}$$



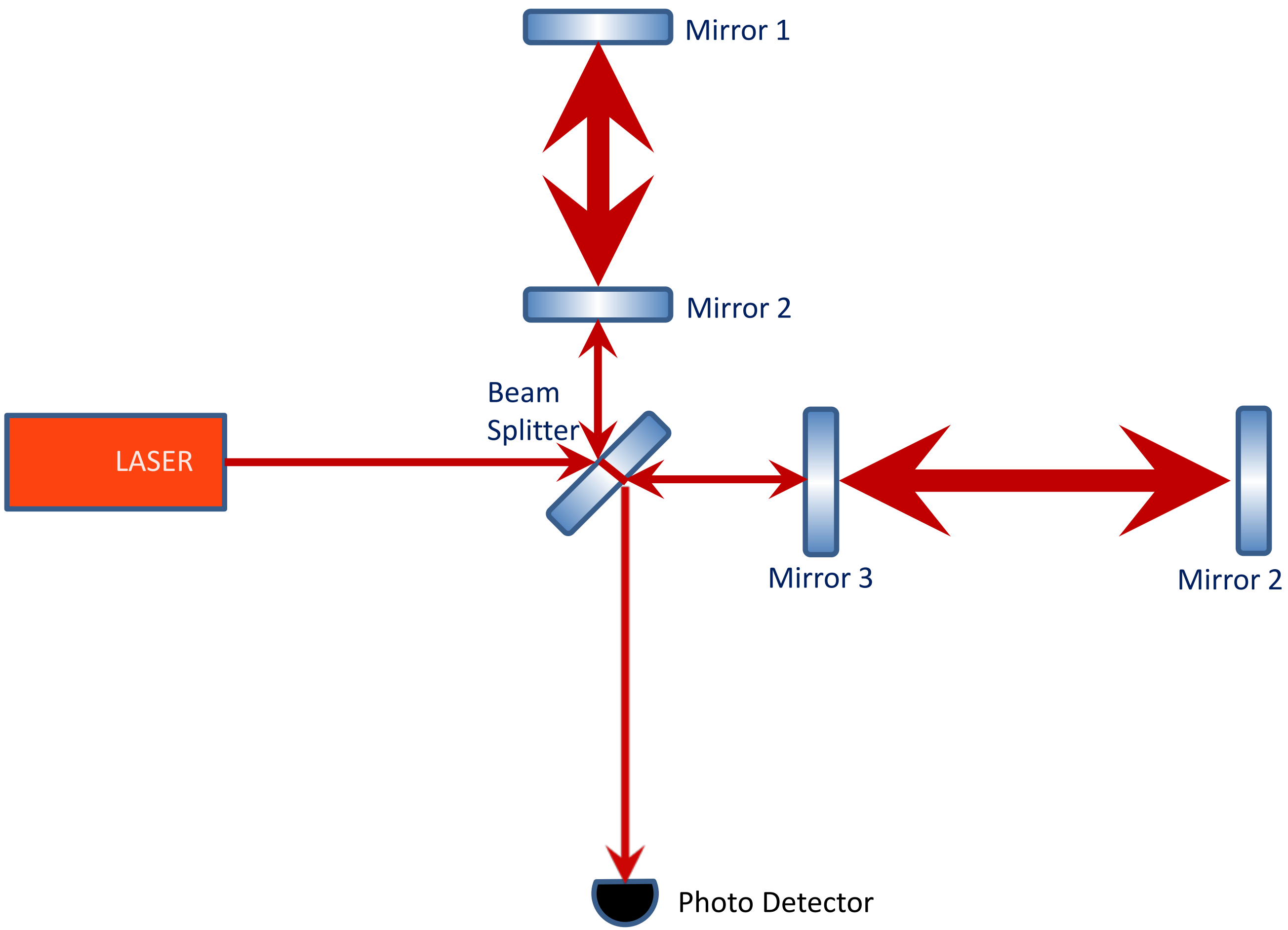
4000,0000000000000000004 m
Effect of a strong GW
h = 10-22
3999,9999999999999999996 m
Haar
Atom
Proton

World-wide Interferometer Network

Simple Michelson Interferometer

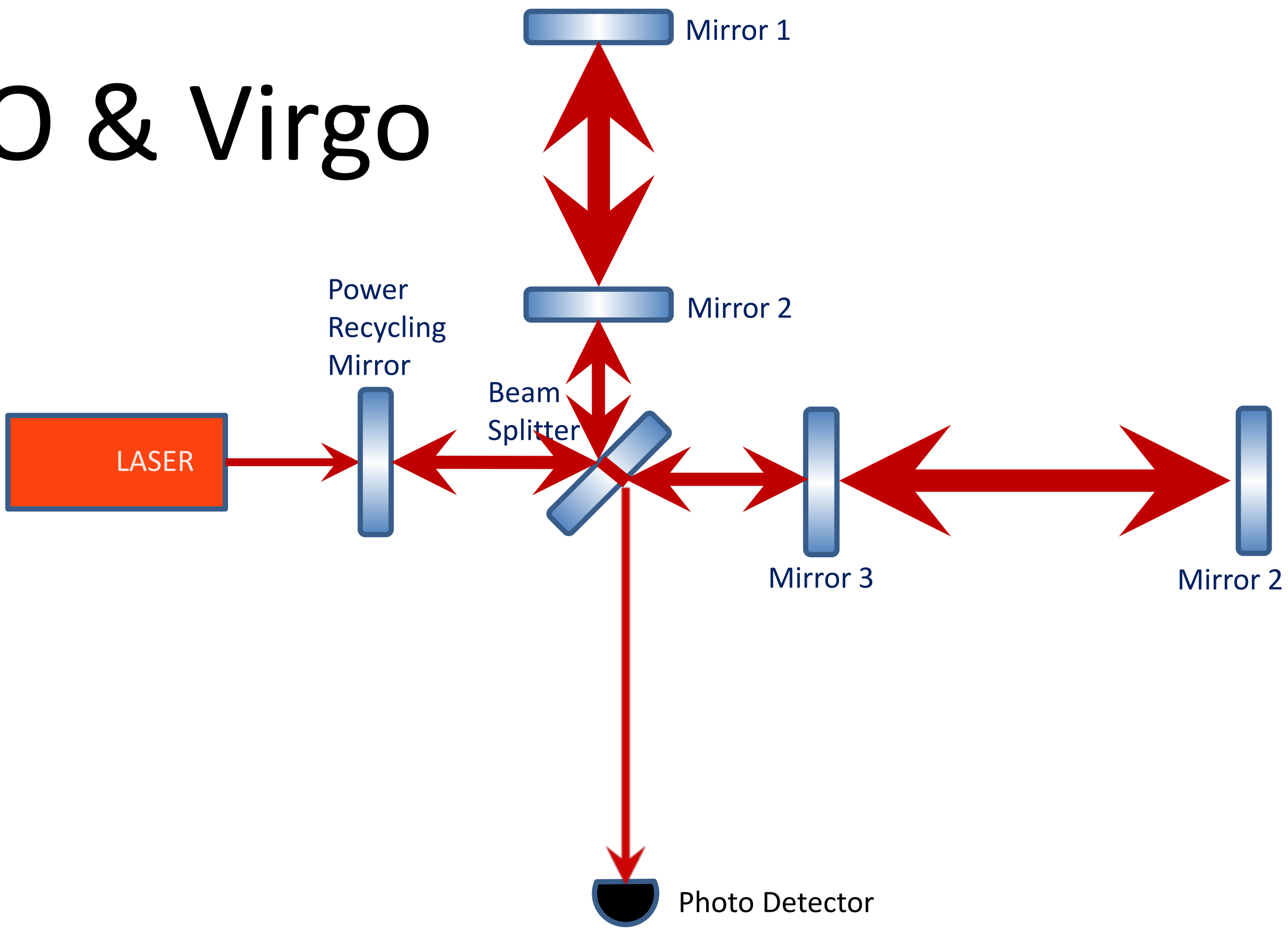


Michelson with arm cavities



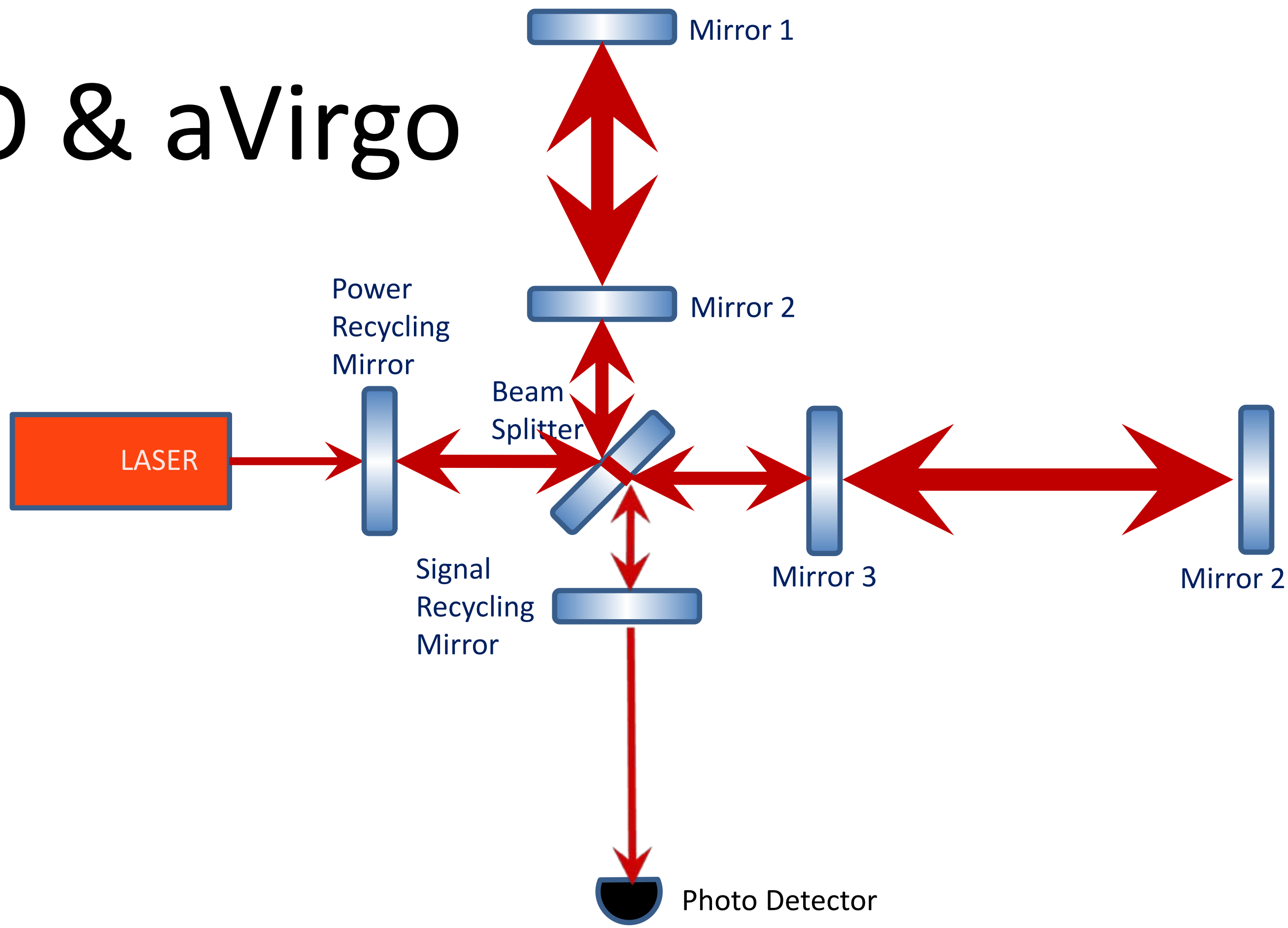
Michelson with arm cavities + PR

LIGO & Virgo



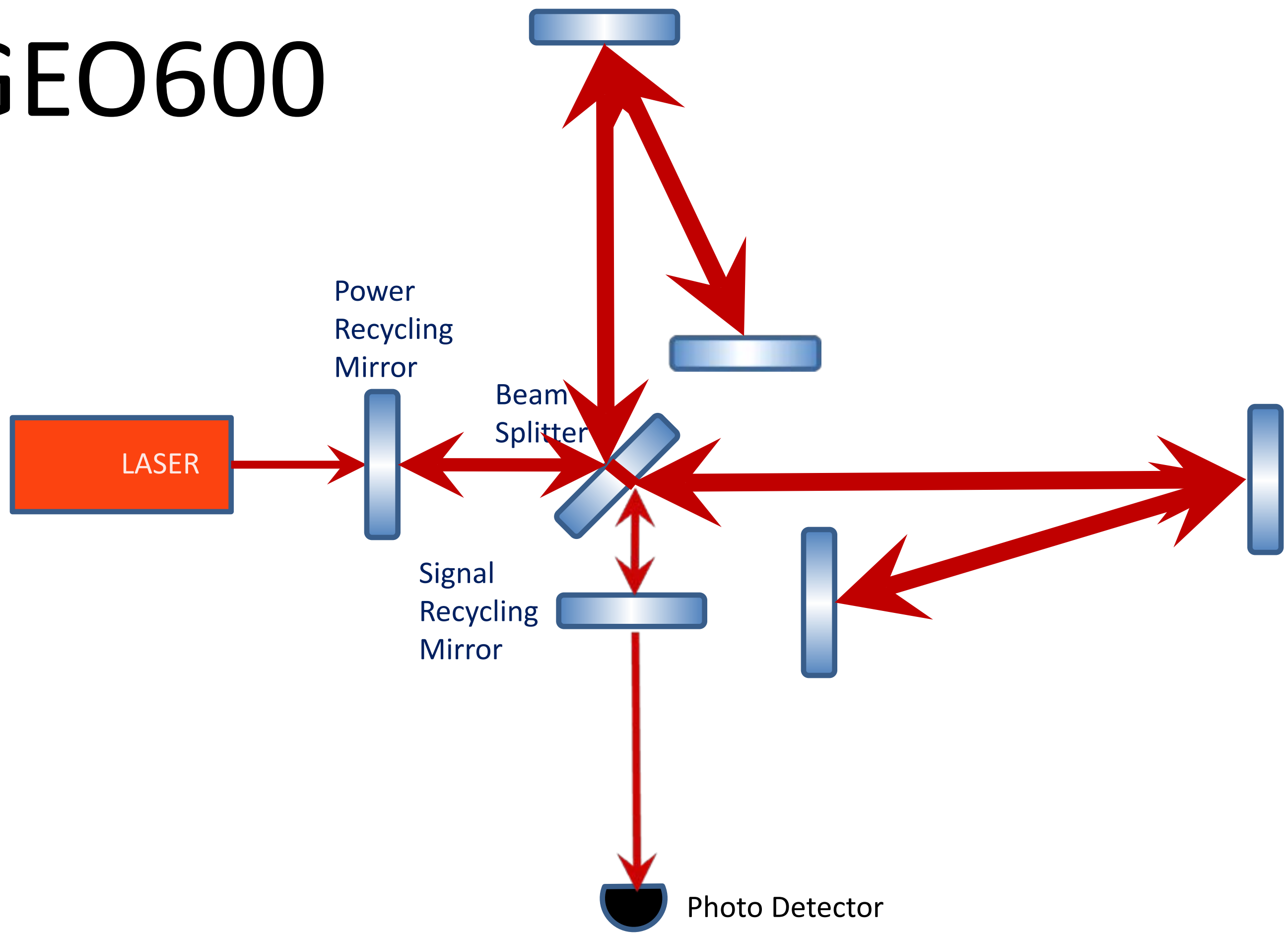
Michelson with arm cavities + DR

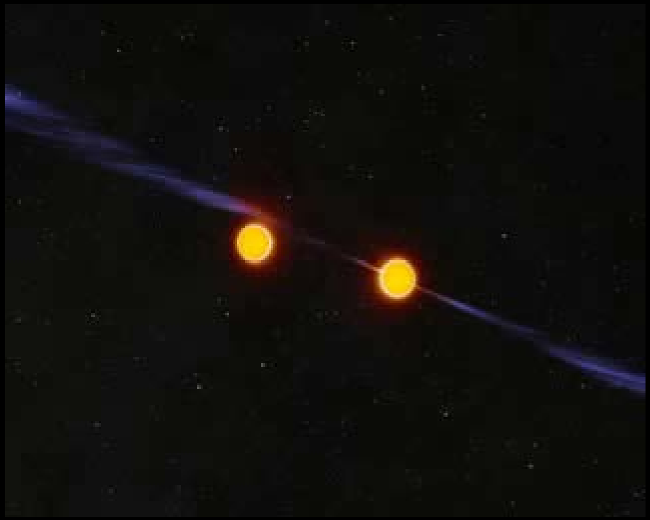
aLIGO & aVirgo

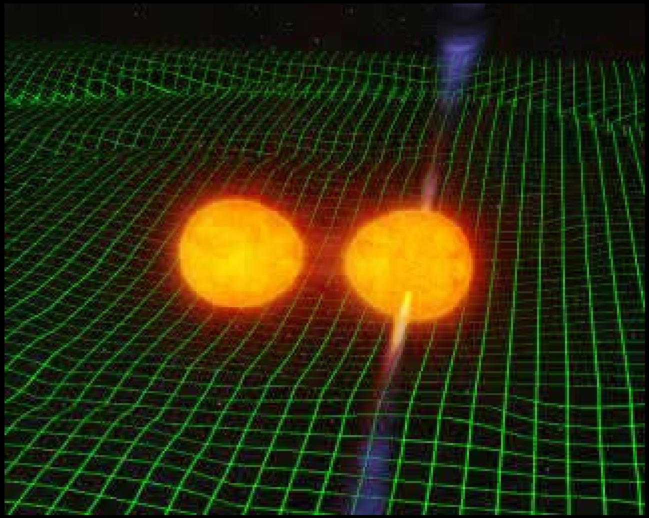


Michelson with DR

GEO600



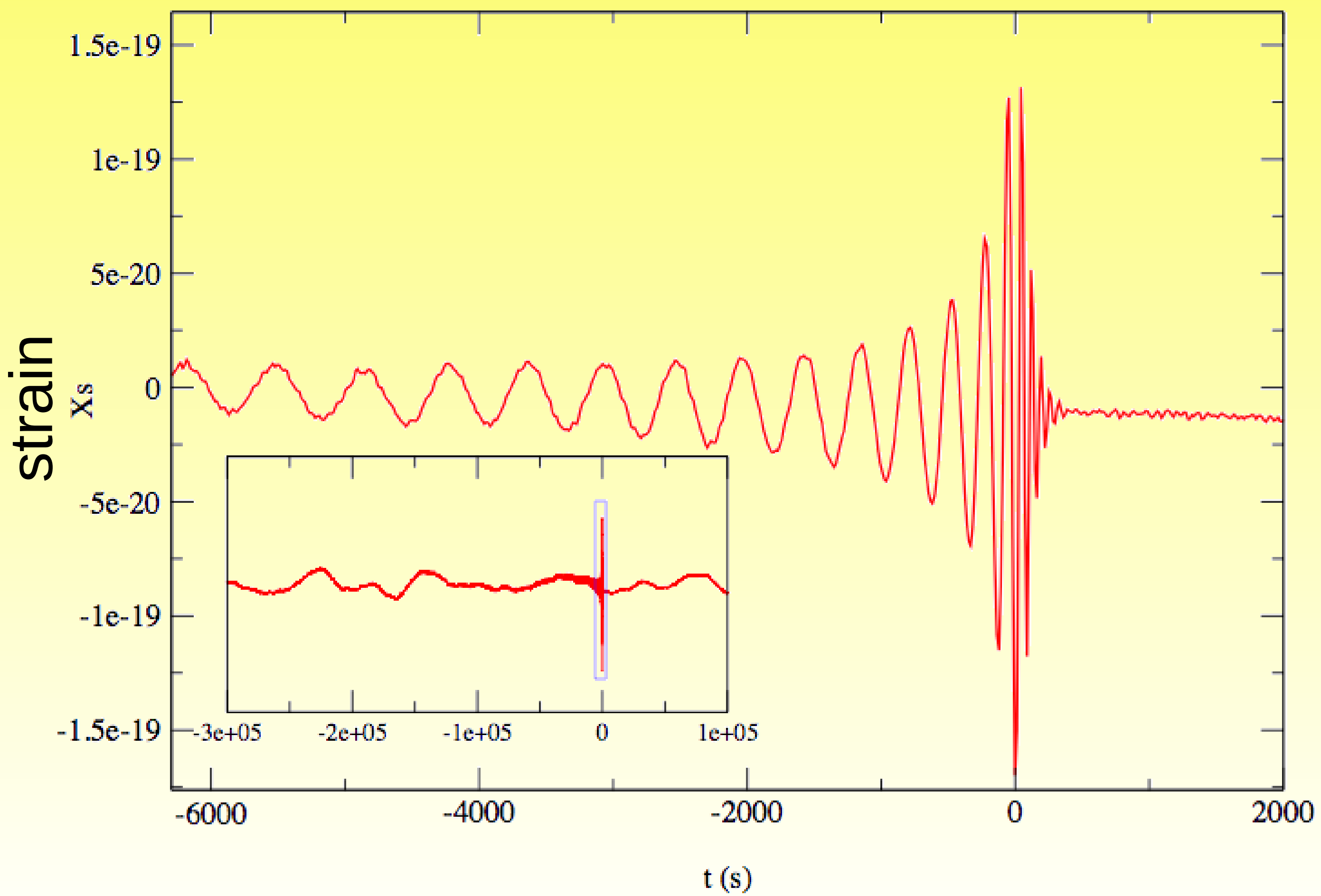




Courtesy CSIRO

Merger Signals far above Noise

- Simulated data stream for LISA,
  - $10^5 M_\odot$ BH binary merger at z=5, including instrumental noise (SNR~500)



Rate estimates

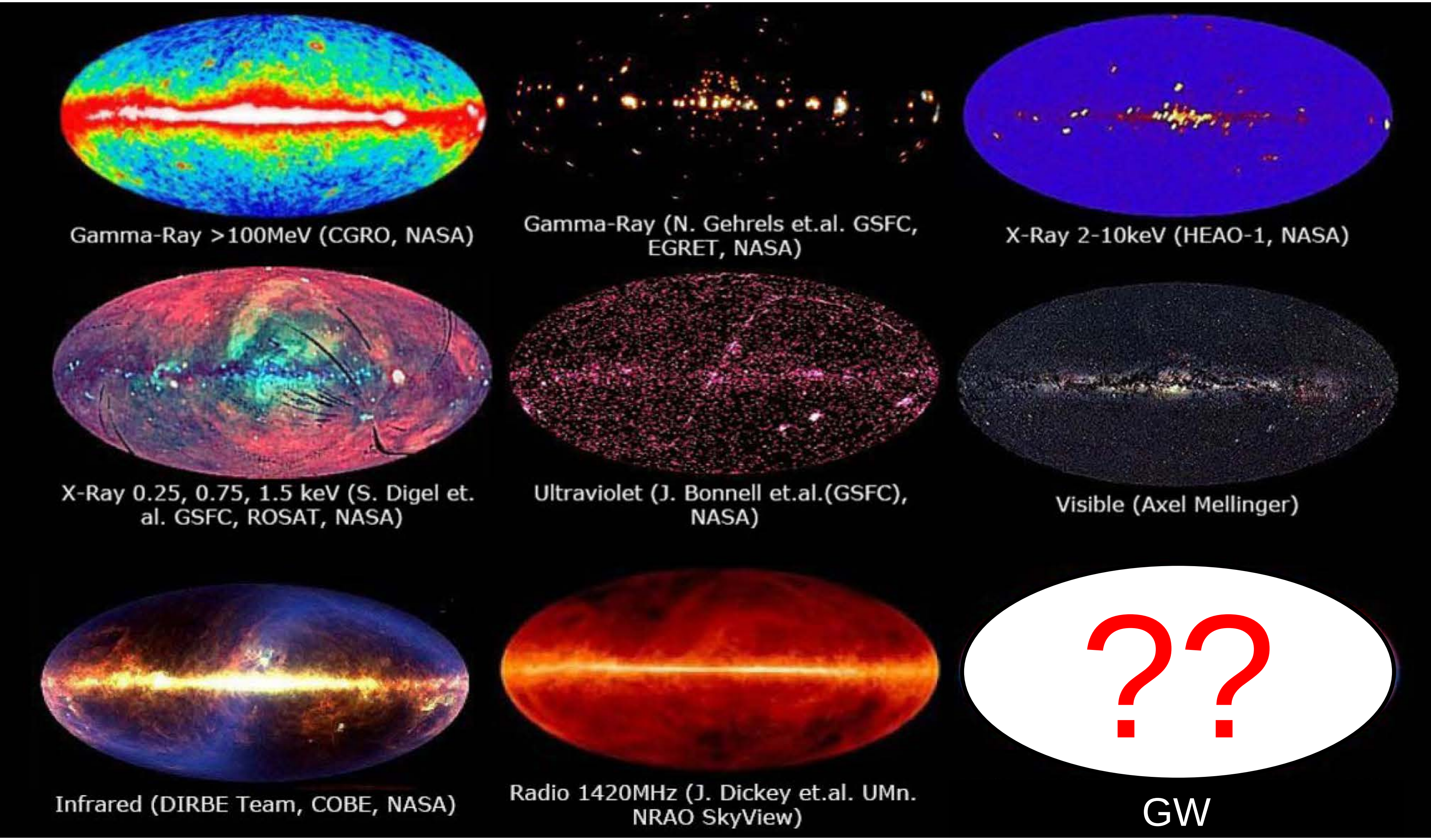
Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			<0.001[b]	0.01[c]
	IMBH-IMBH			10^{-4}[d]	10^{-3}[e]
	NS–NS	0.4	40	400	1000
	NS–BH	0.2	10	300	
Advanced	BH–BH	0.4	20	1000	
	IMRI into IMBH			10[b]	300[c]
	IMBH-IMBH			0.1[d]	1[e]

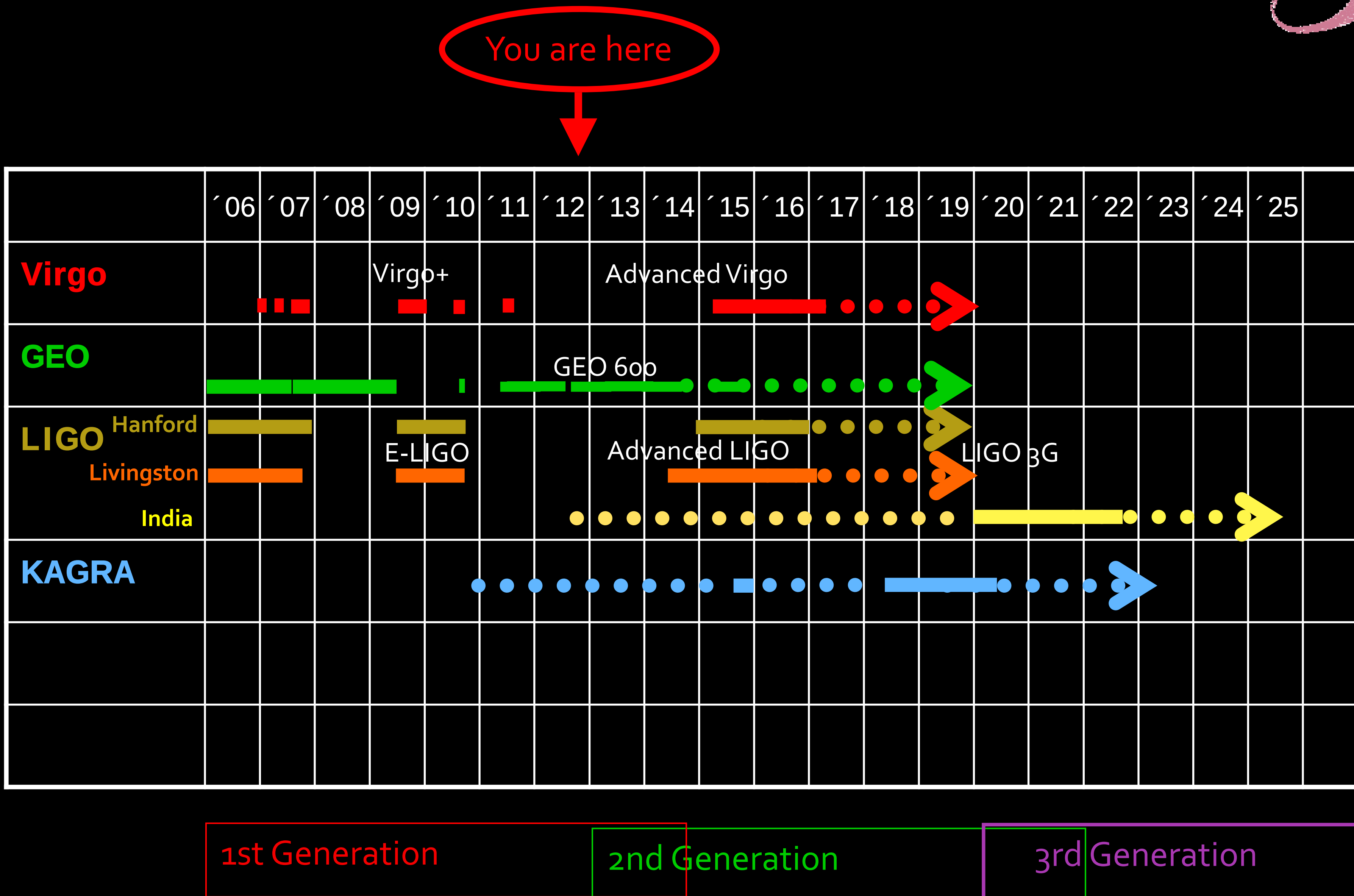
From: http://iopscience.iop.org/0264-9381/27/17/173001

VIEWS OF THE UNIVERSE

From: http://coolcosmos.ipac.caltech.edu

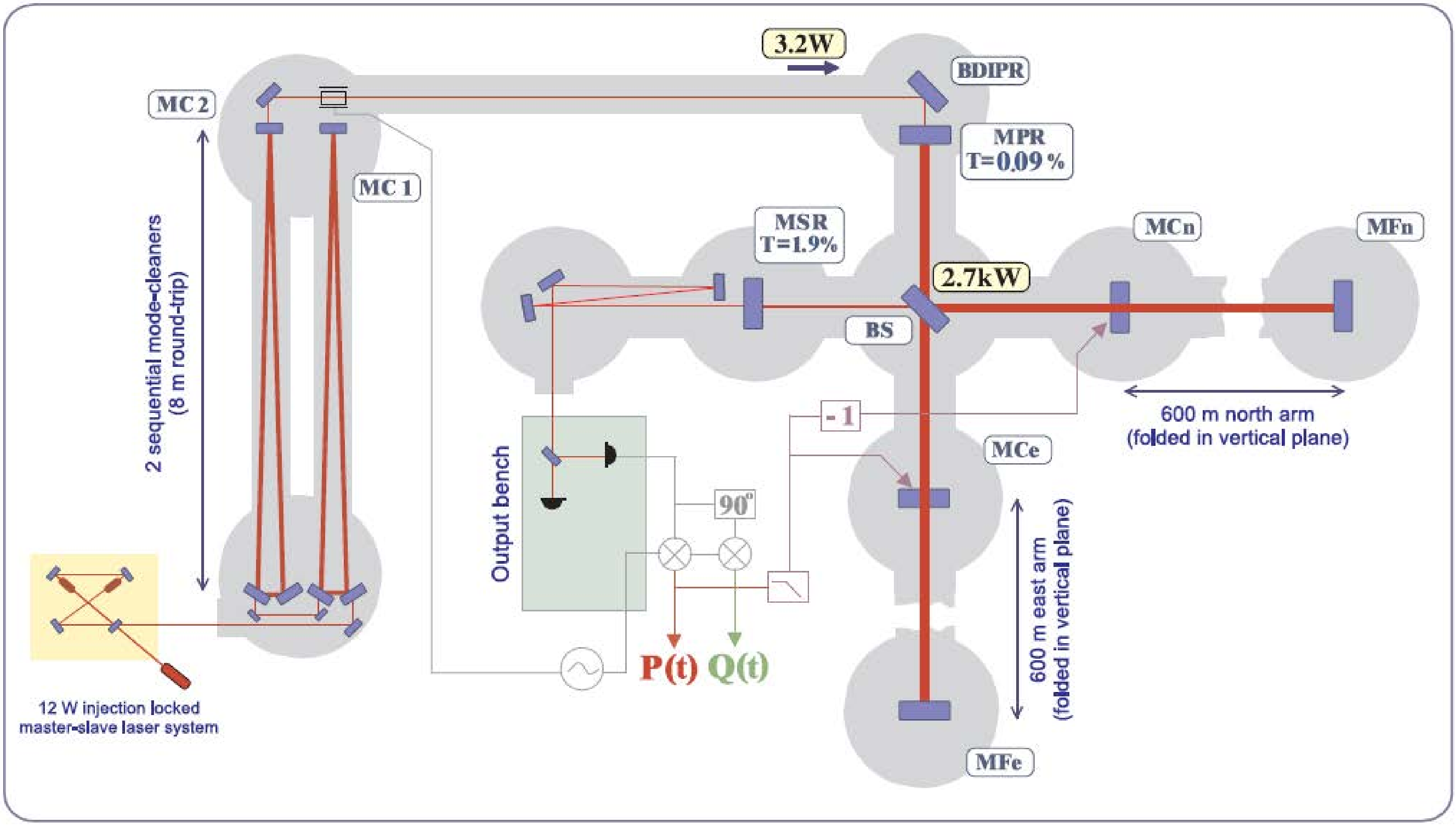


GW Timelines

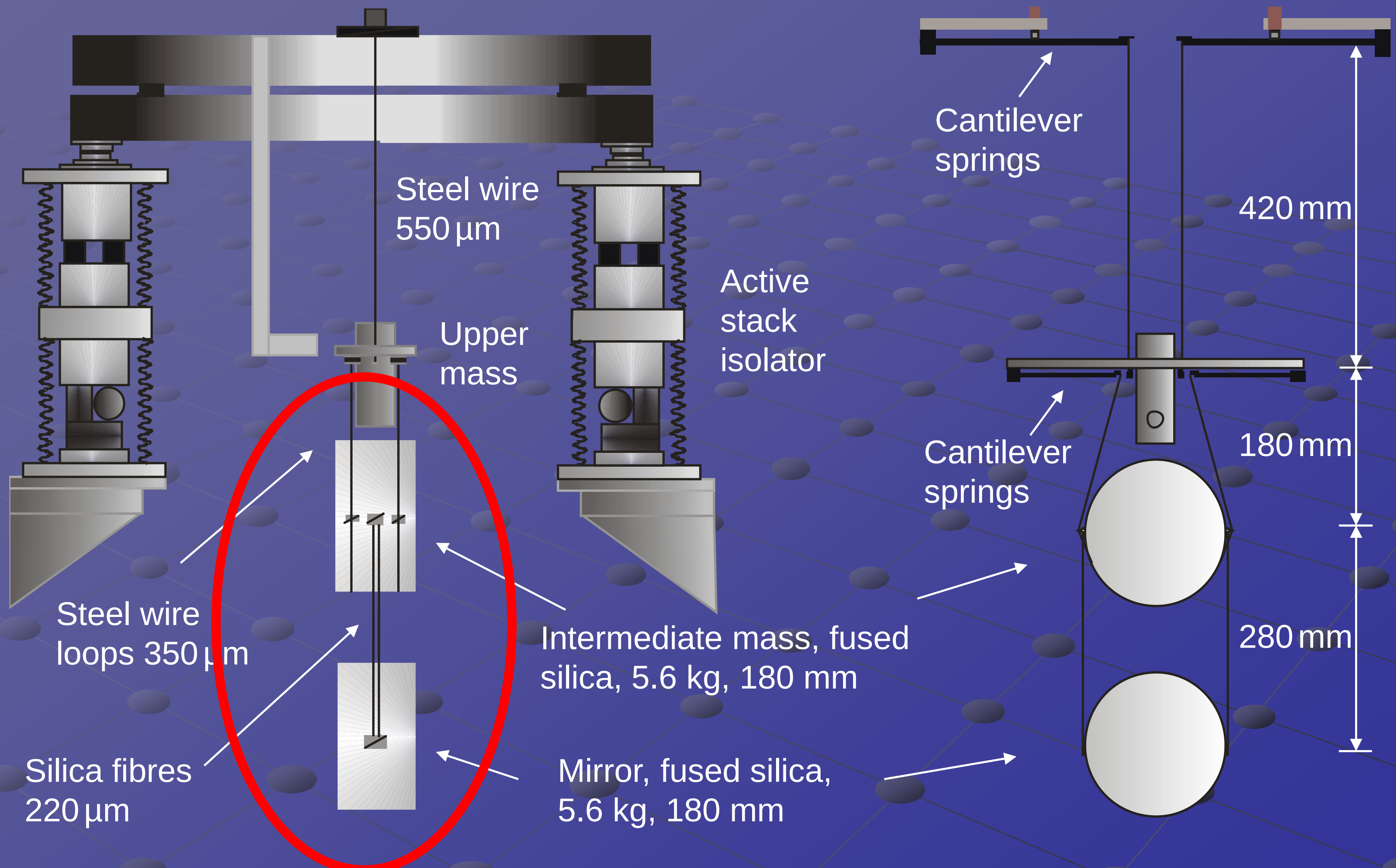


GEO600

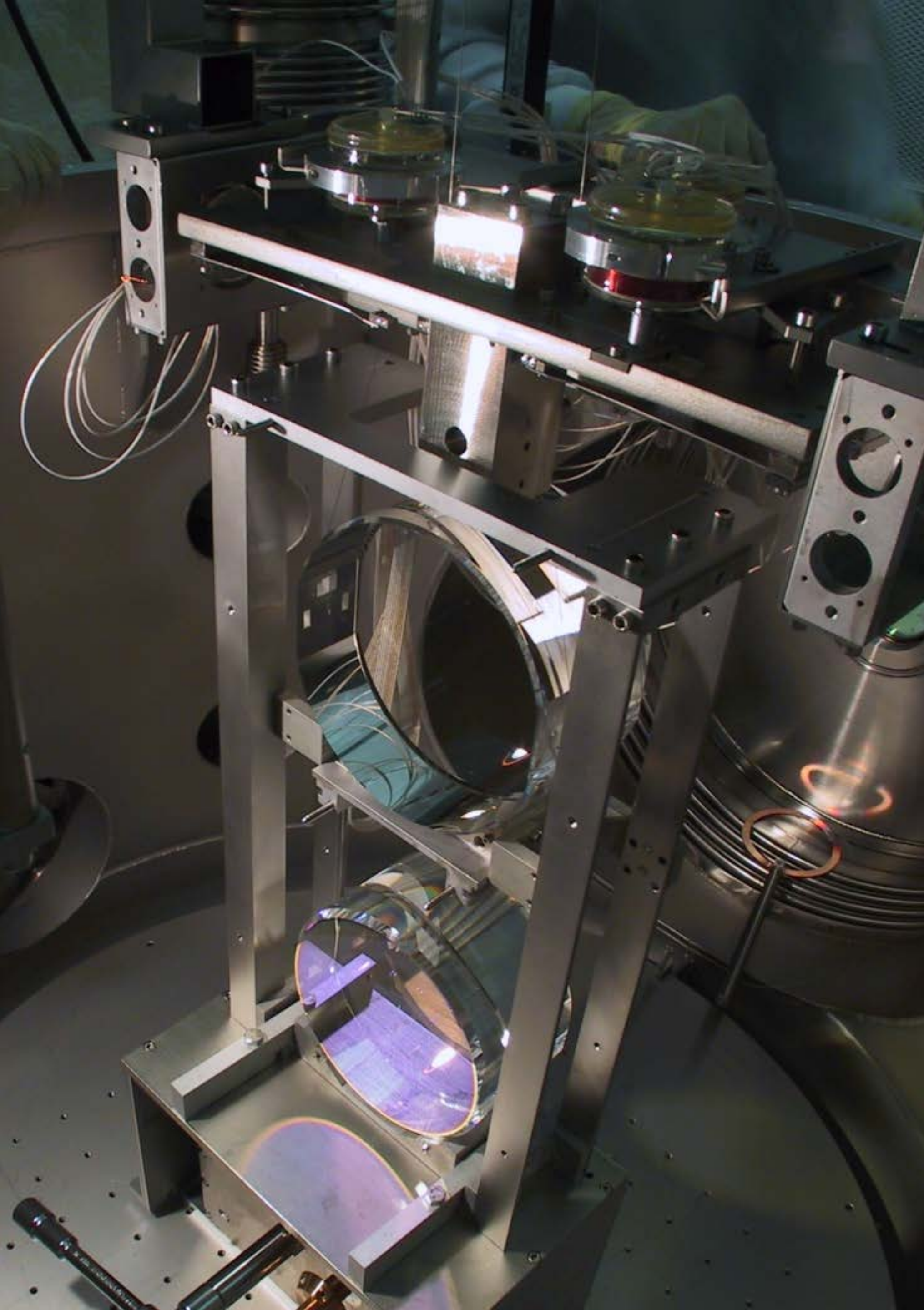
The GEO6oo Interferometer



GEO 600 main suspension



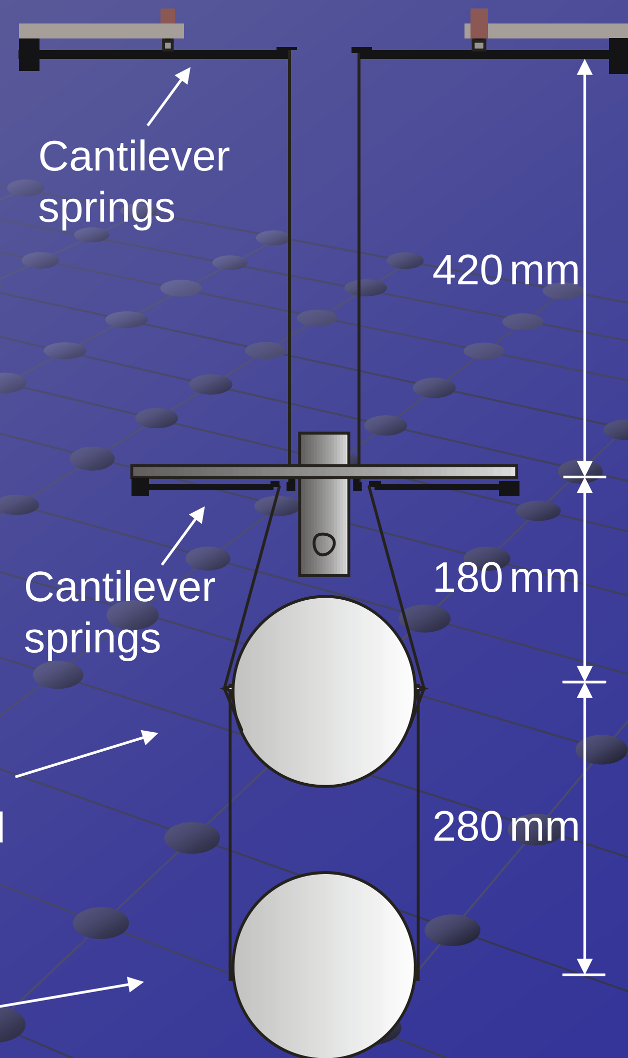
in suspension

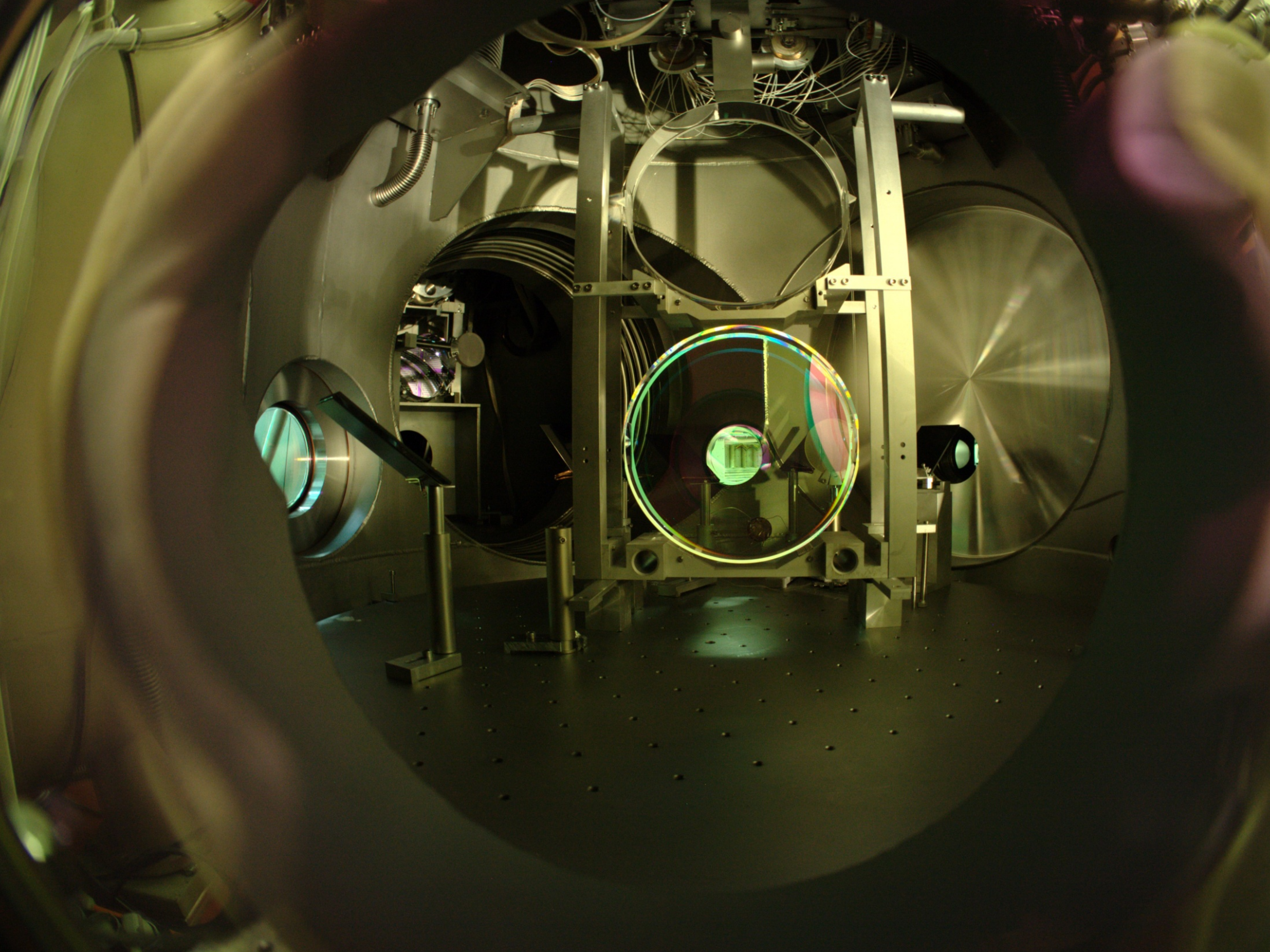


Active
stack
isolator

e mass, fused
, 180 mm

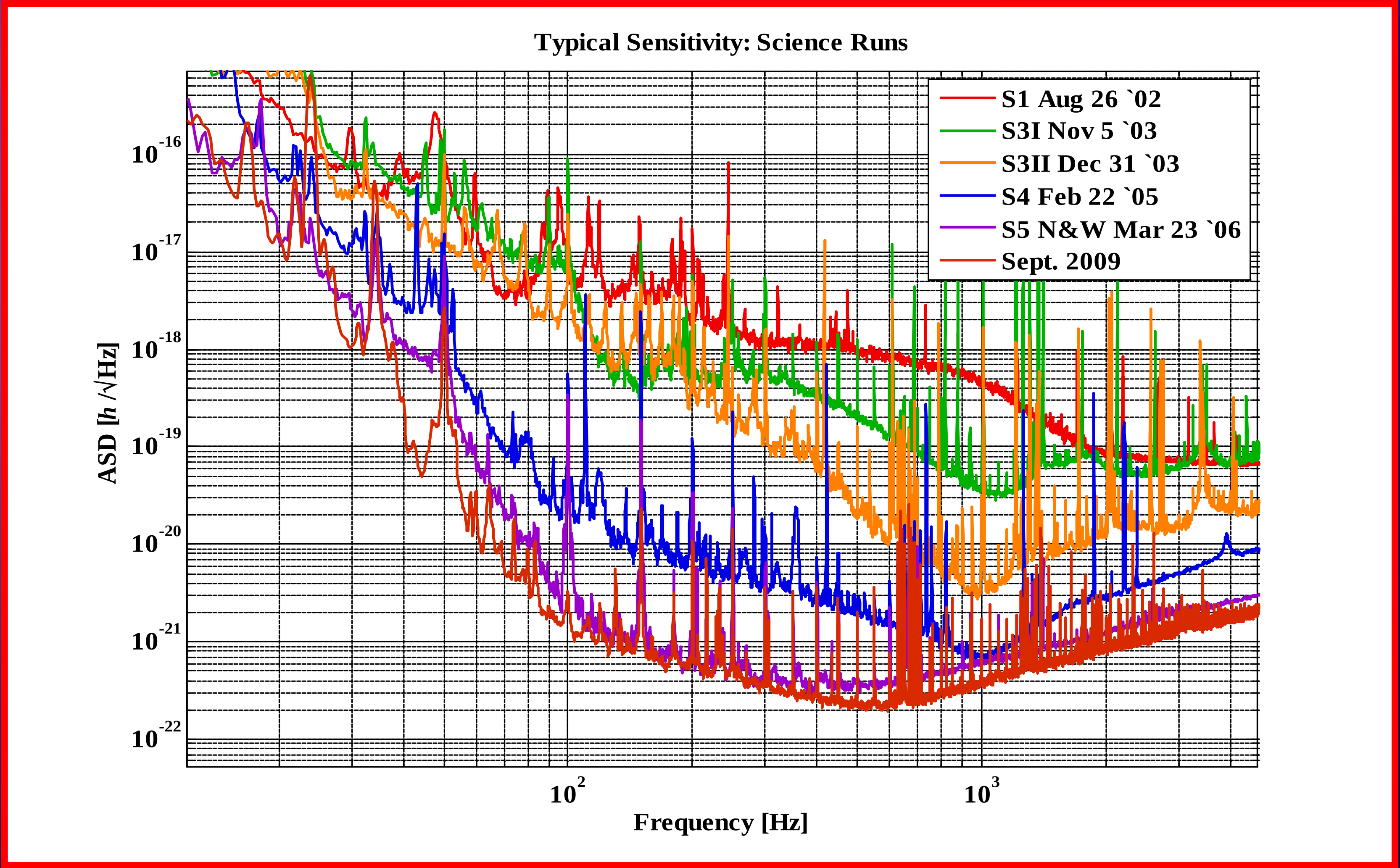
ed silica,
mm



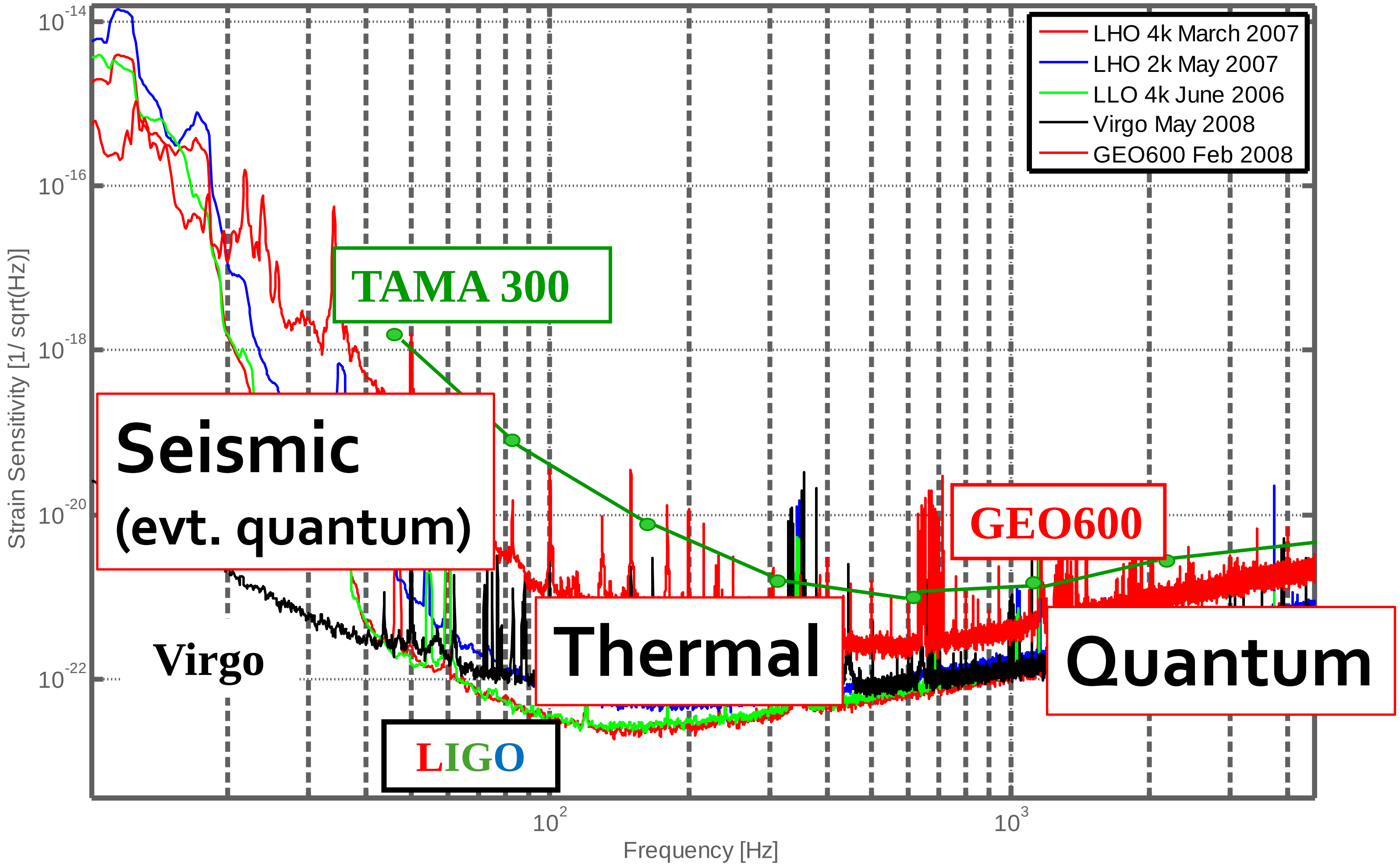


Sensitivity evolution

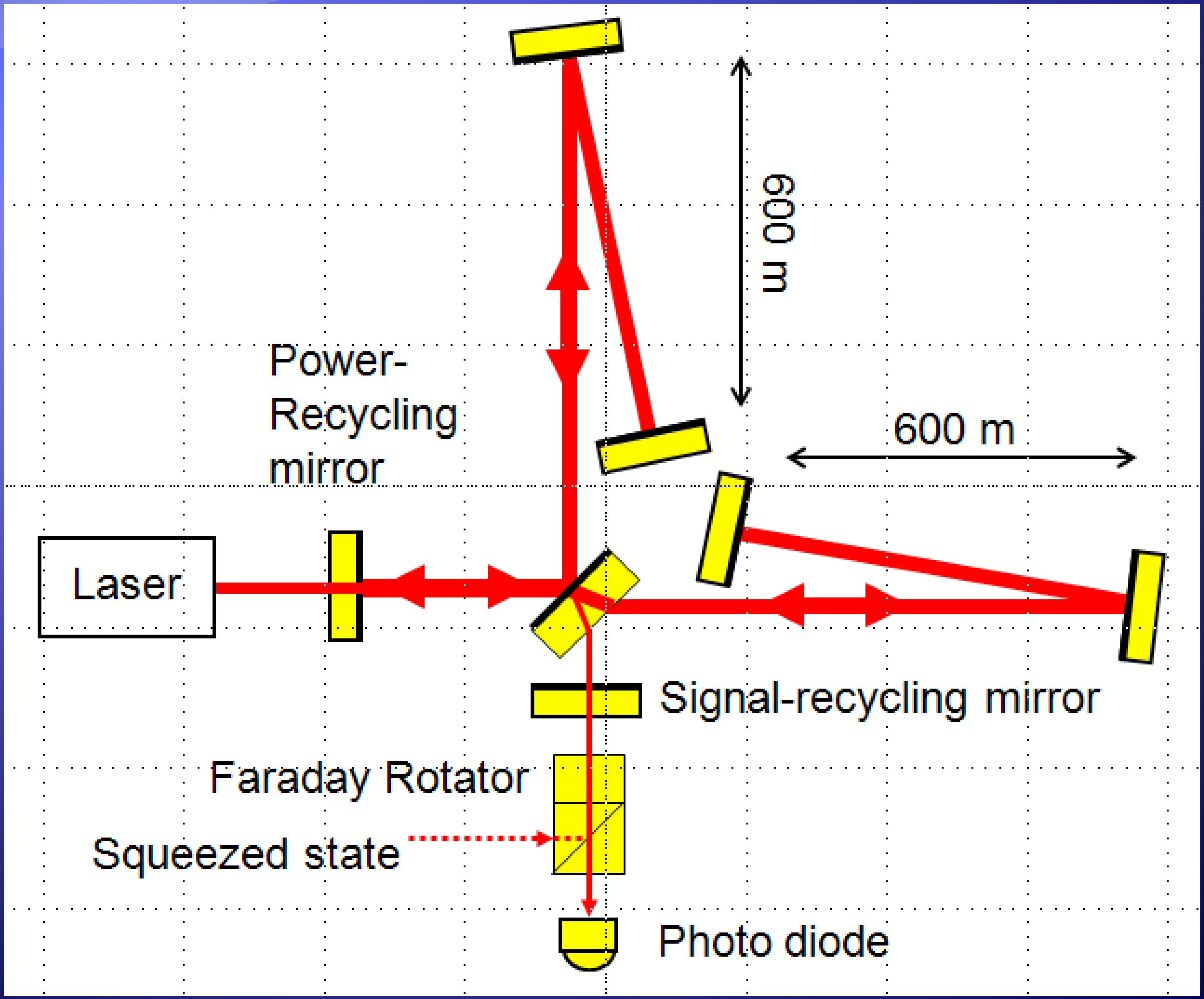
GEO600



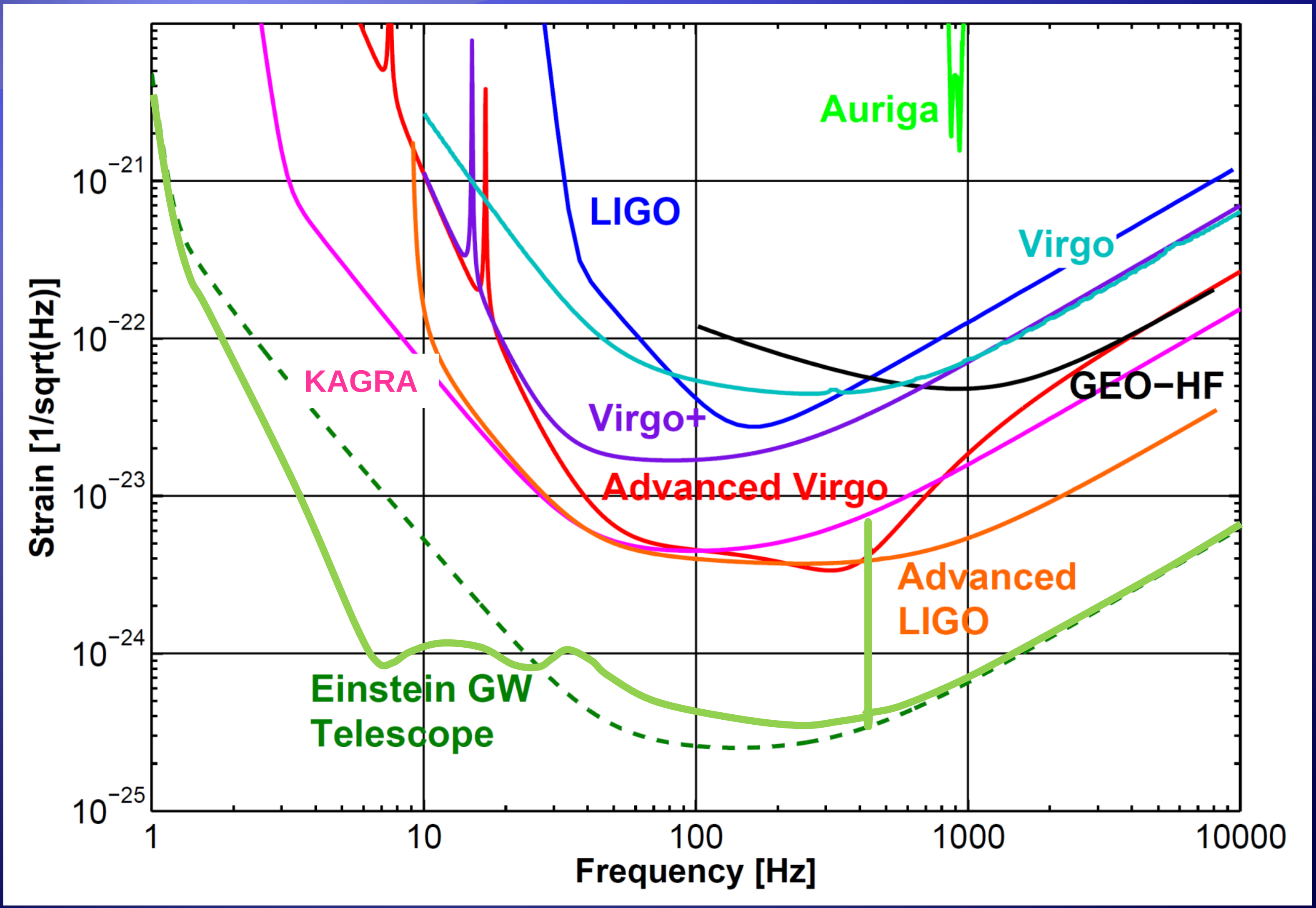
1st Gen. Sensitivities



Quantum noise reduction in GEO600

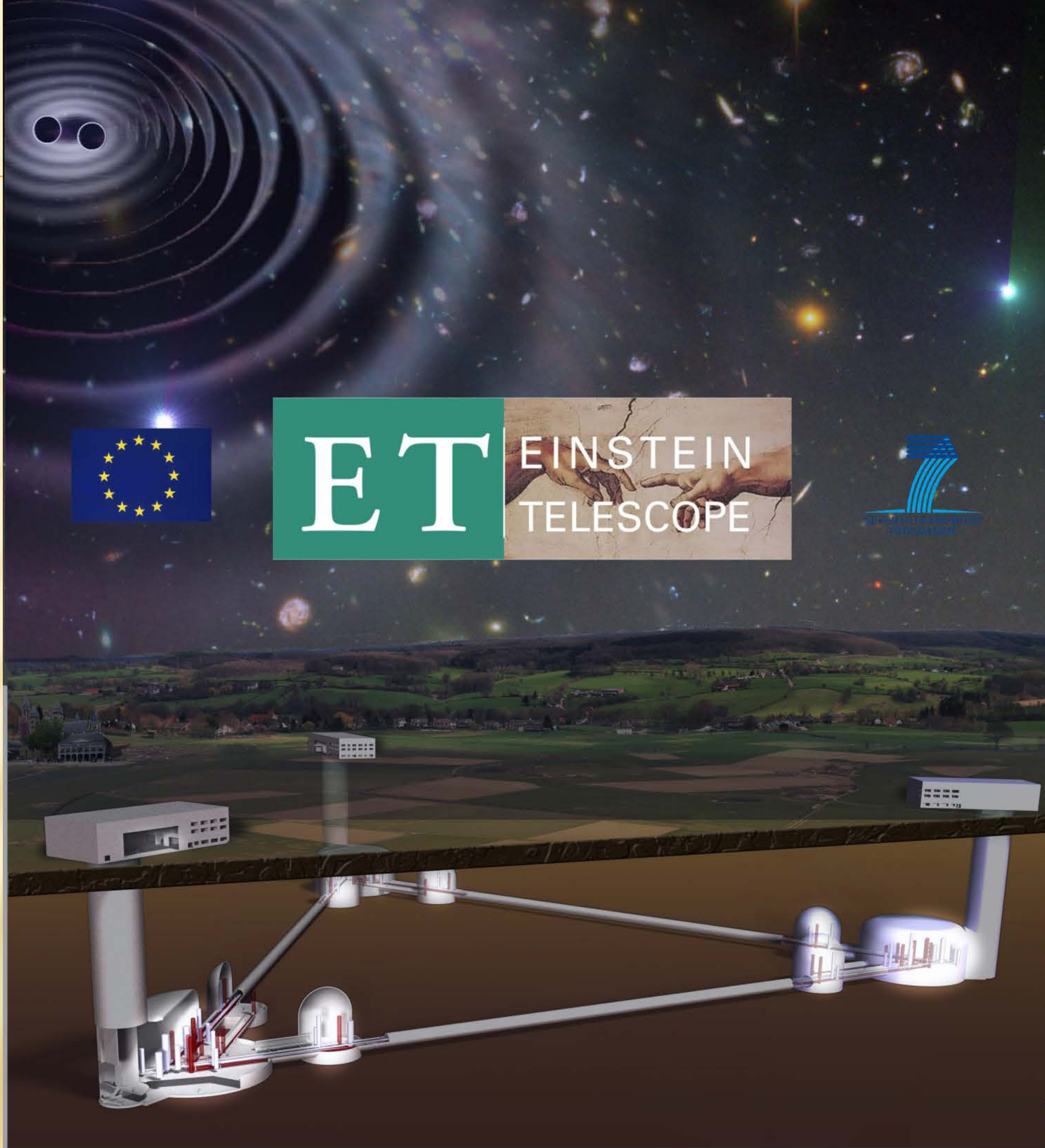


Sensitivites: now & then

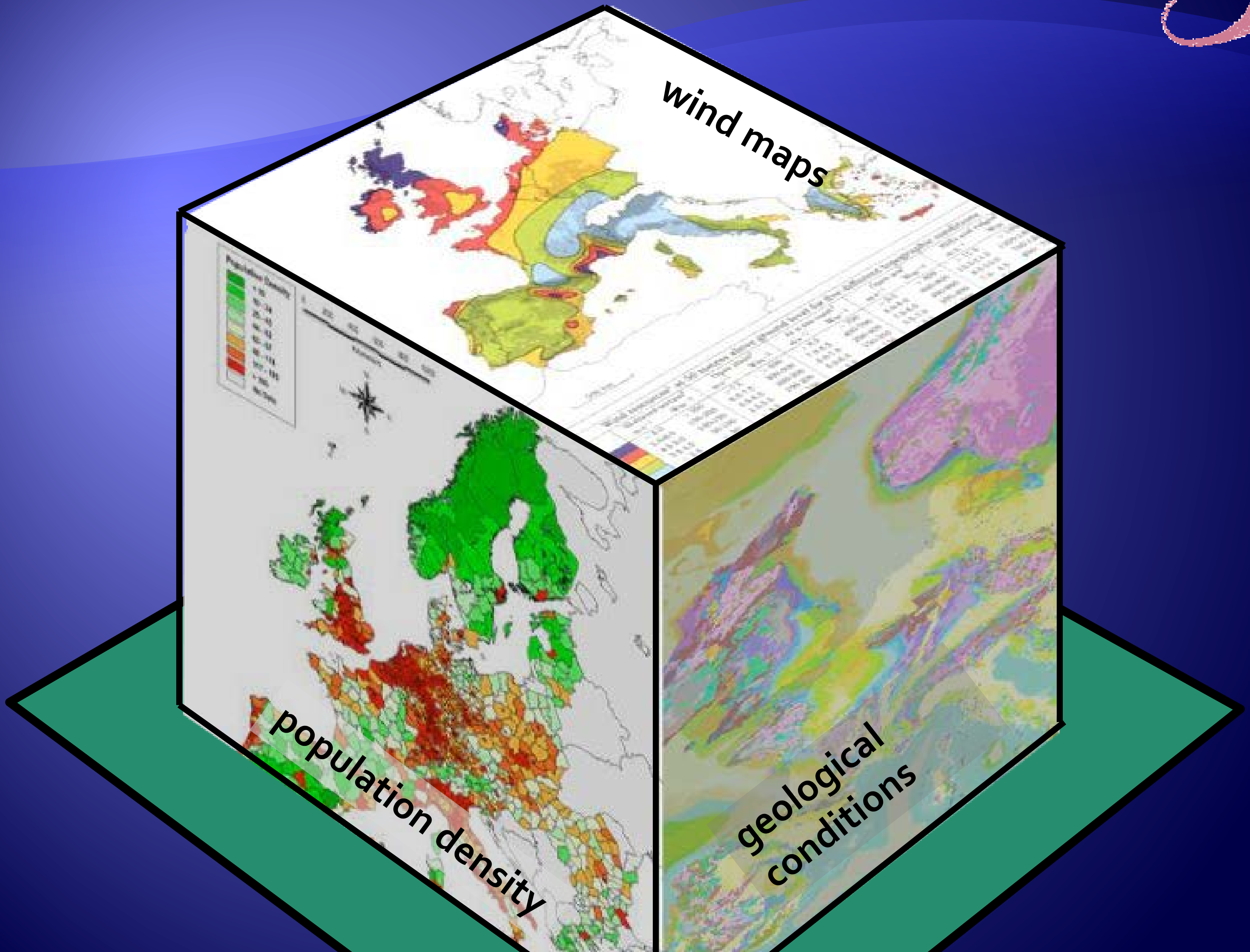


ET

EINSTEIN TELESCOPE

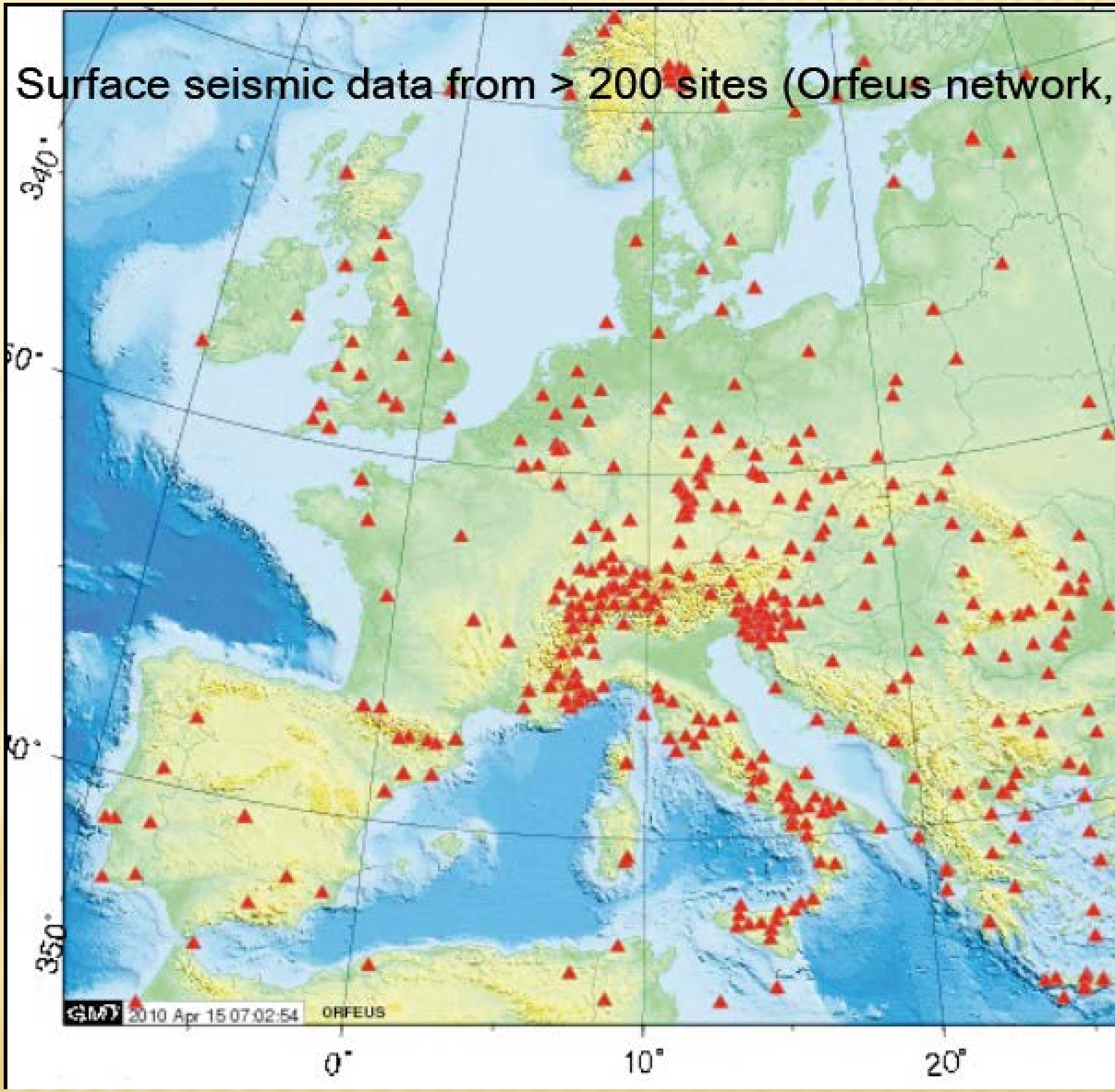


Site selection aspects



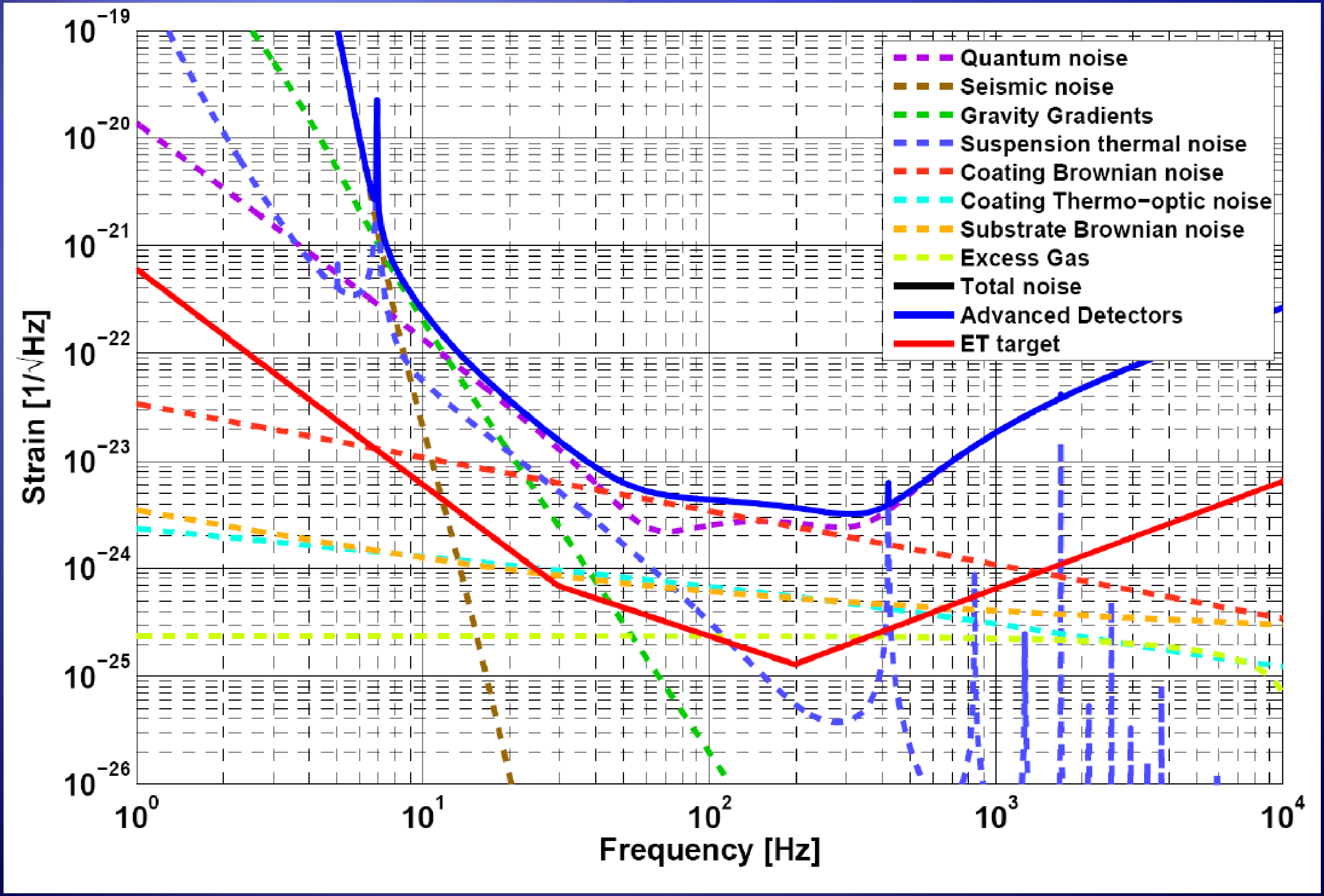
SEISMOLOGY NETWORK

- Site investigation also used the support and the data of the ORFEUS* Network (>200 sites in Europe)



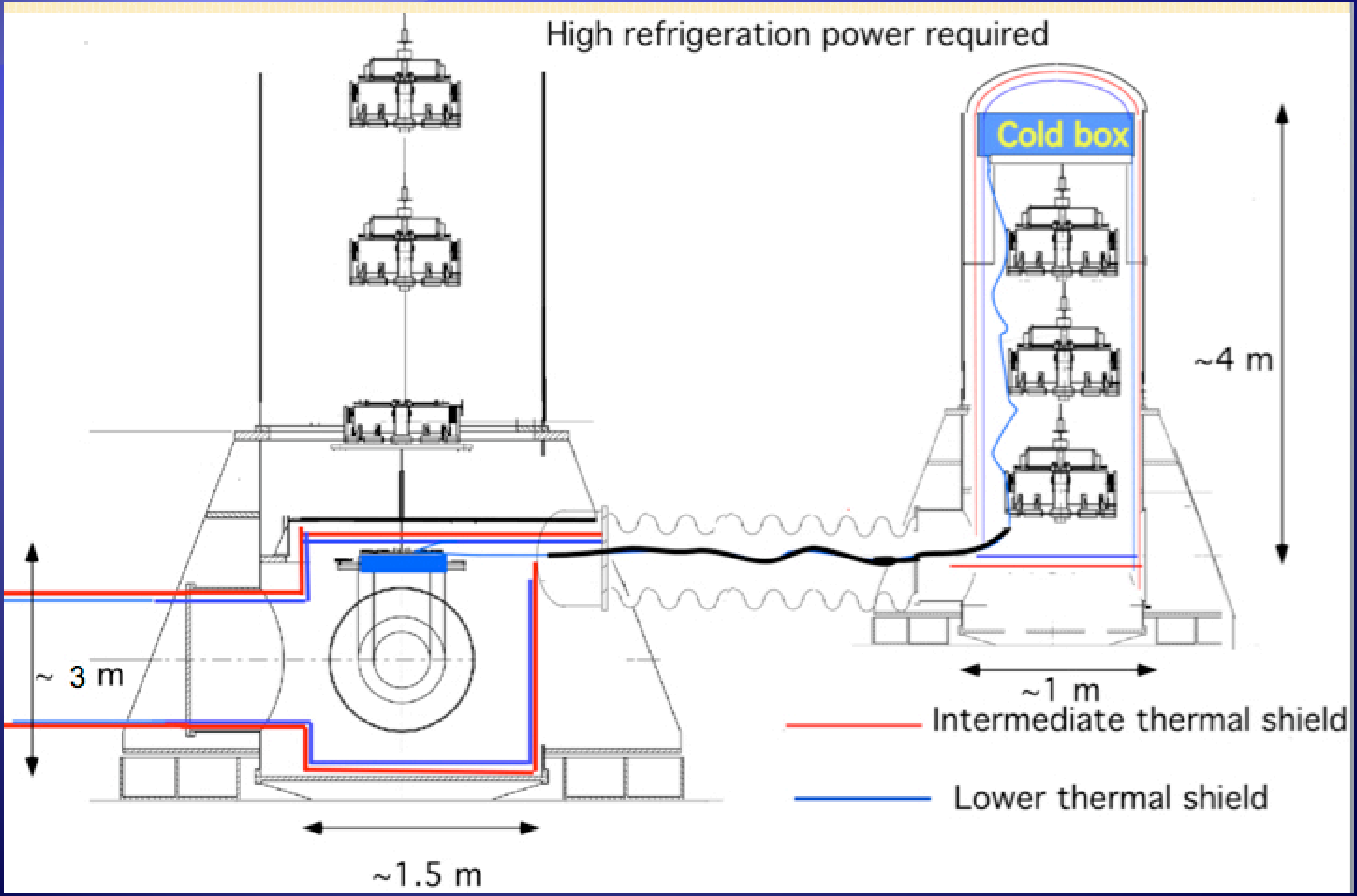
* Observatories and Research Facilities for European Seismology

Noise budget

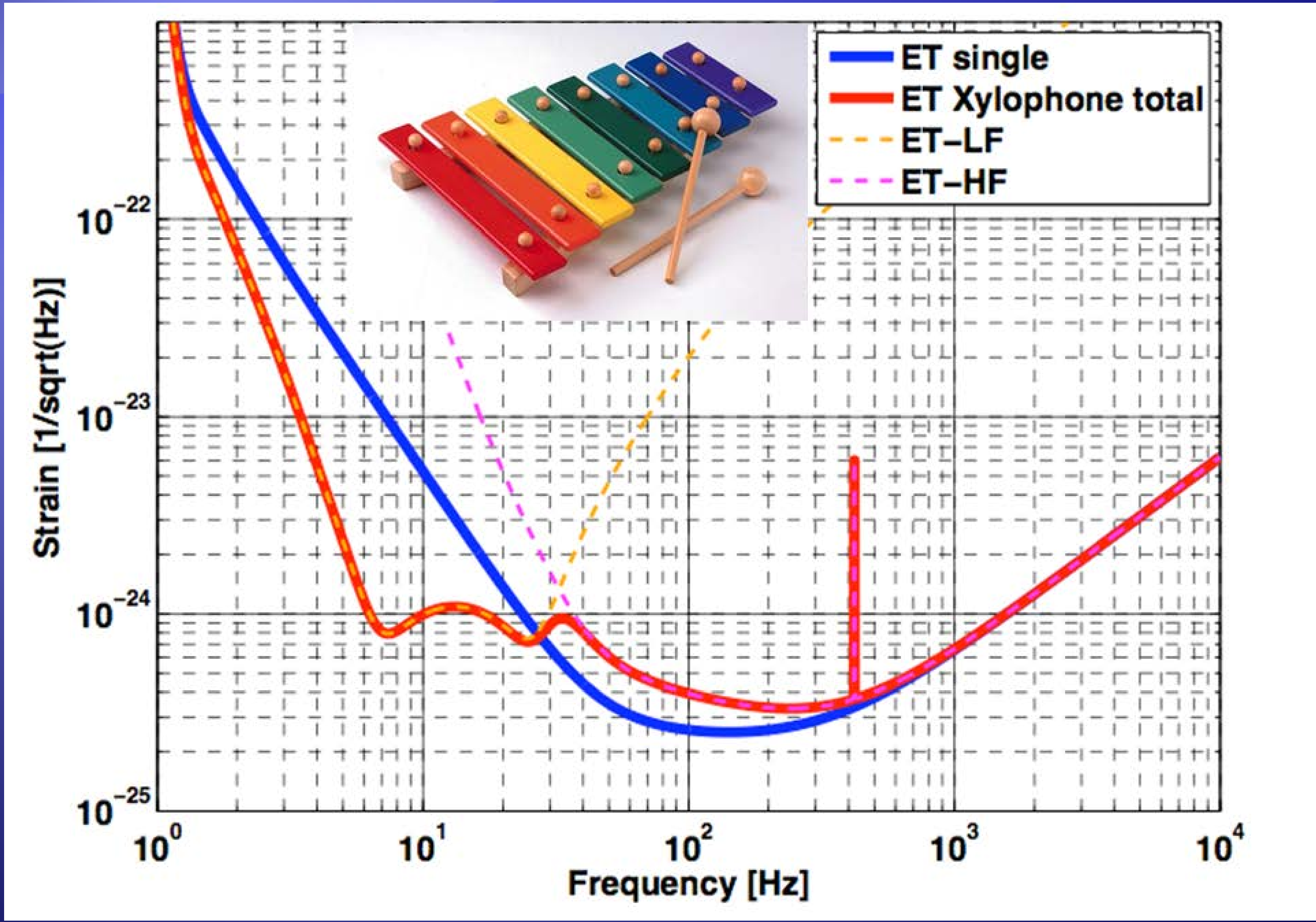


Thermal Noise / Cool Optics

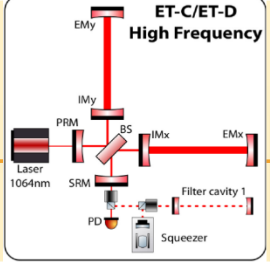
Large, heavy optics ~ 150 kg

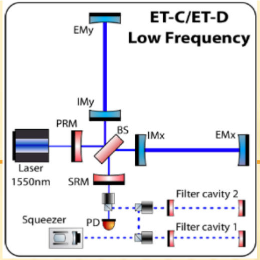


Xylophone: cool & hot



ET PARAMETERS

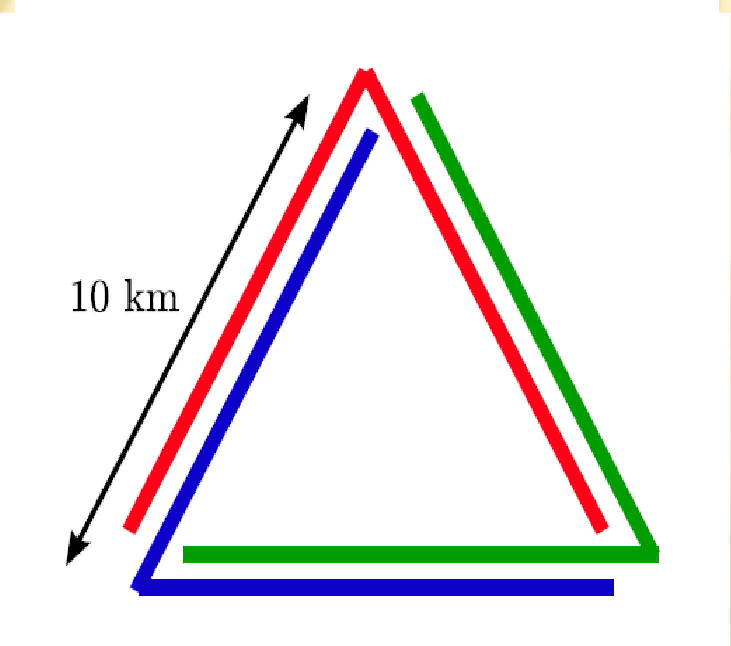


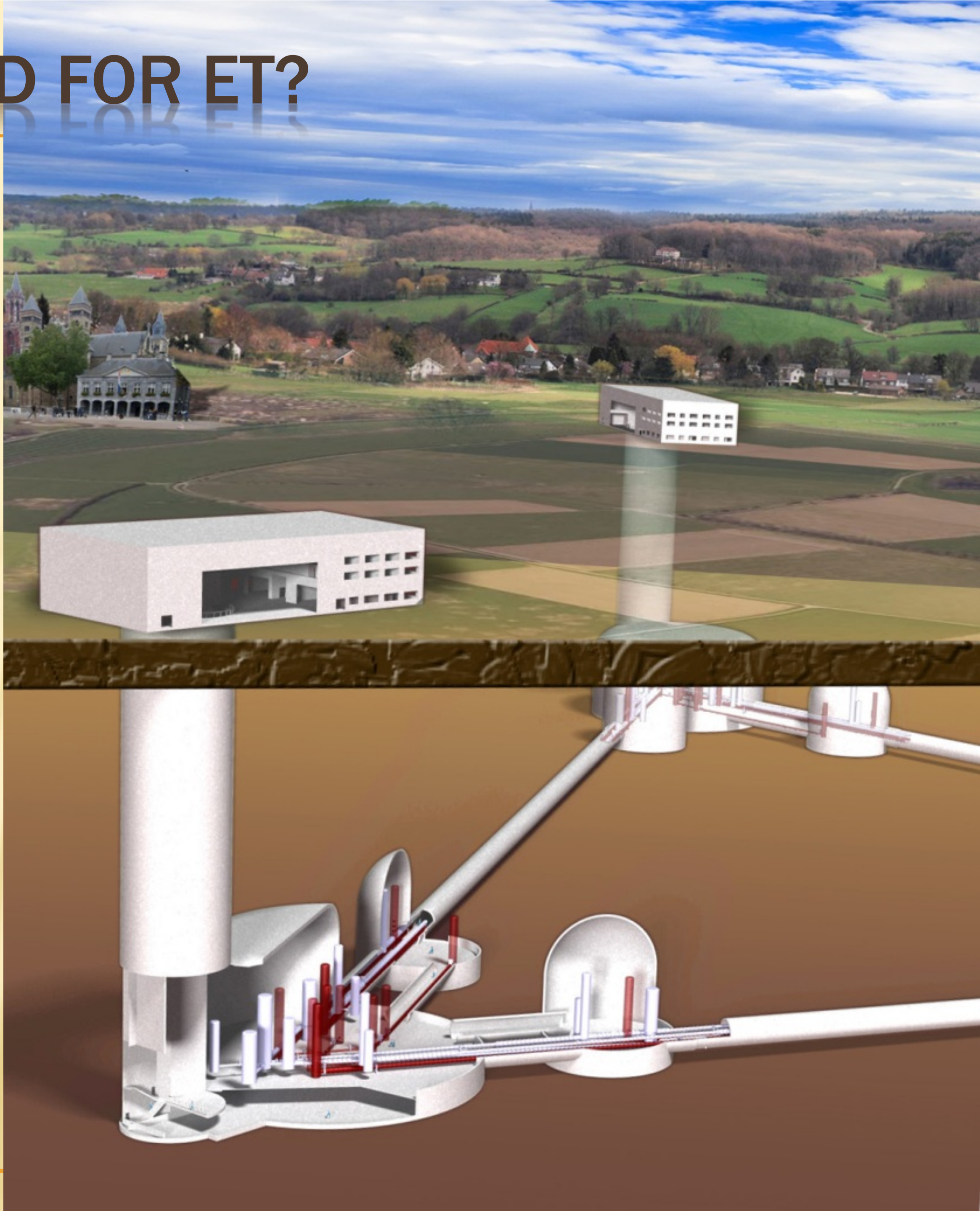


Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ T
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	none

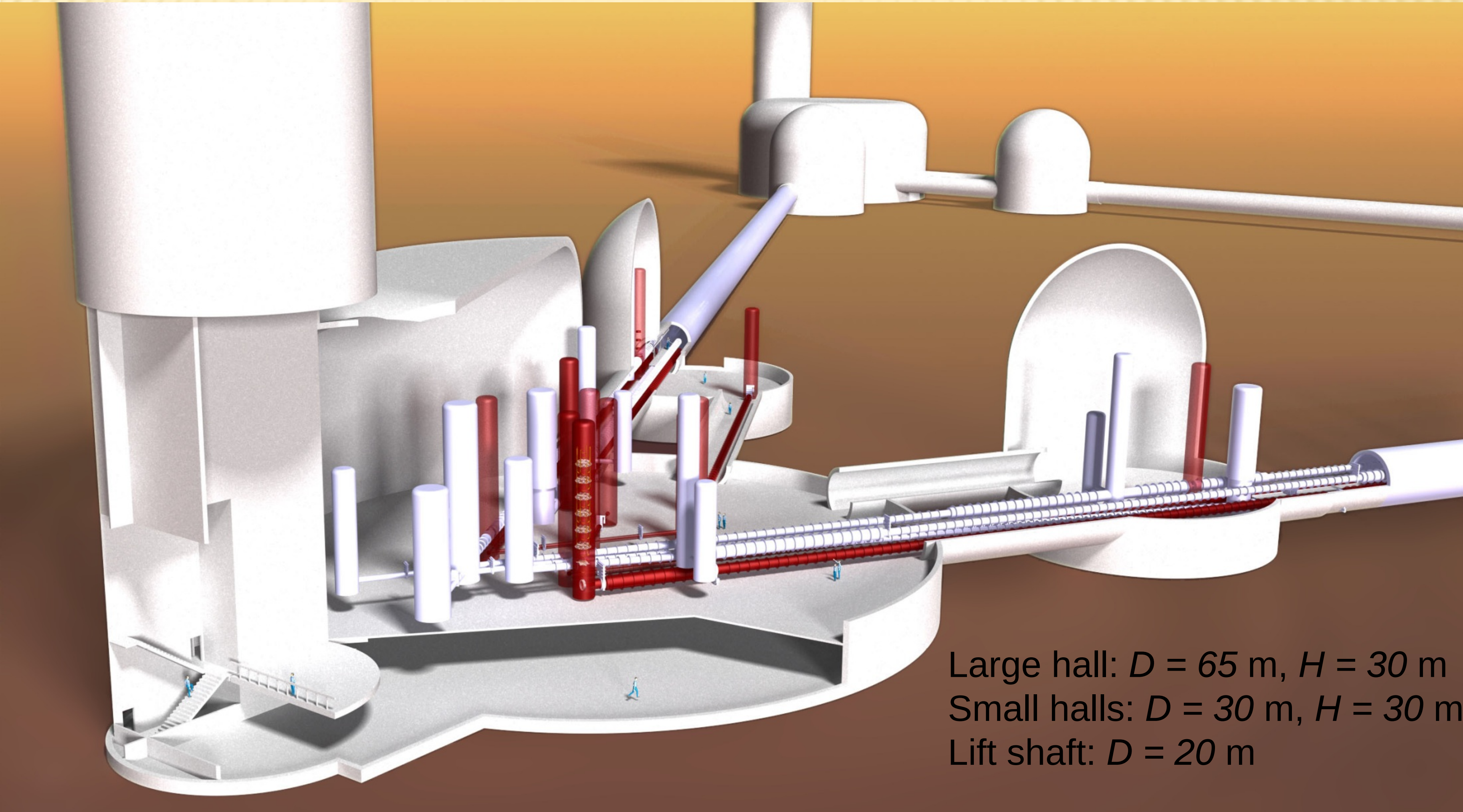
WHAT DO WE NEED FOR ET?
BASIC ET FACTS

- long lasting (decades) infrastructure
- 10km Δ (<displ. Noise)
- 100-200m underground
- „conservative“ design
- Subsequent upgrades to novel techniques



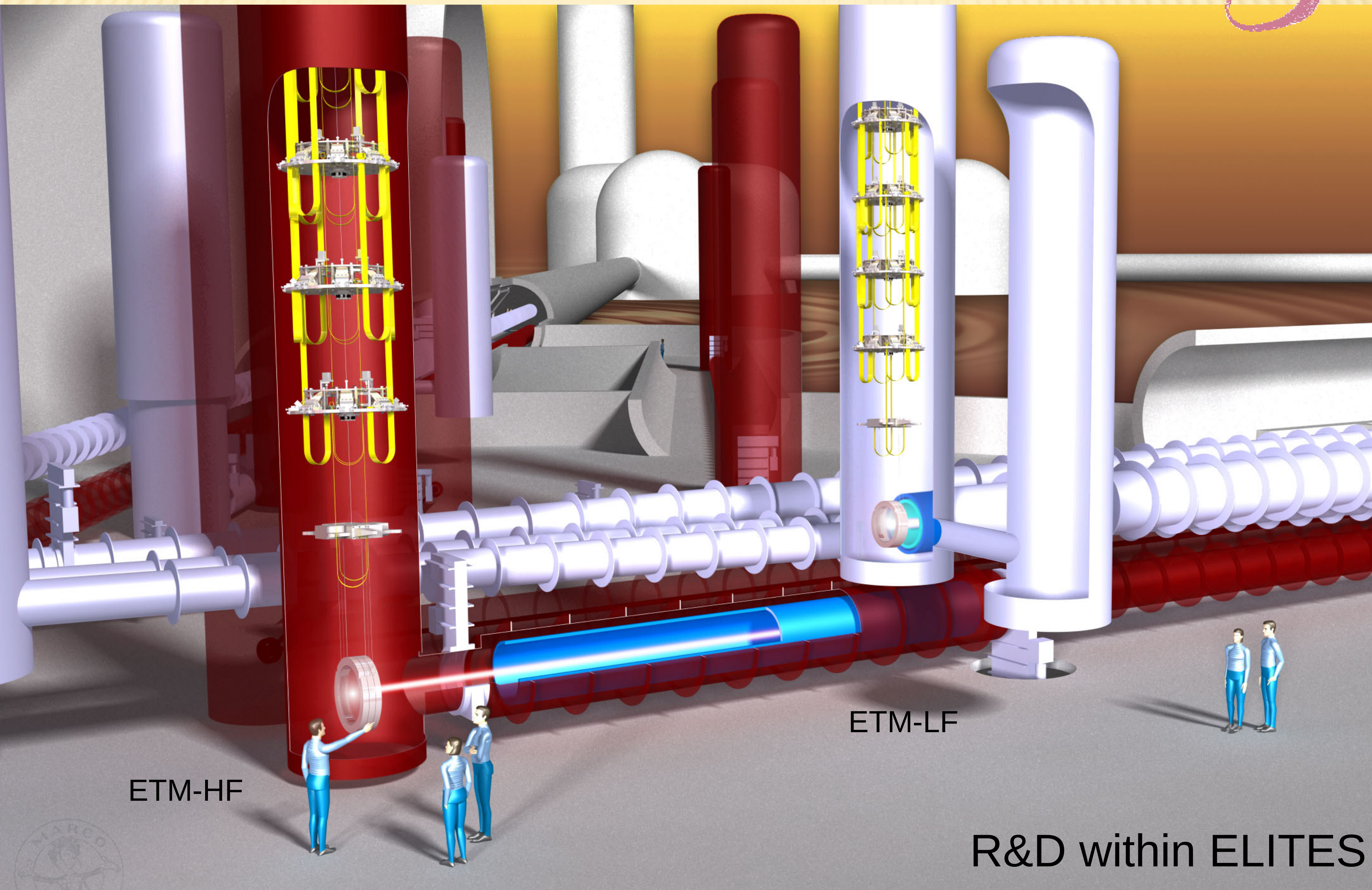


THE INFRASTRUCTURE

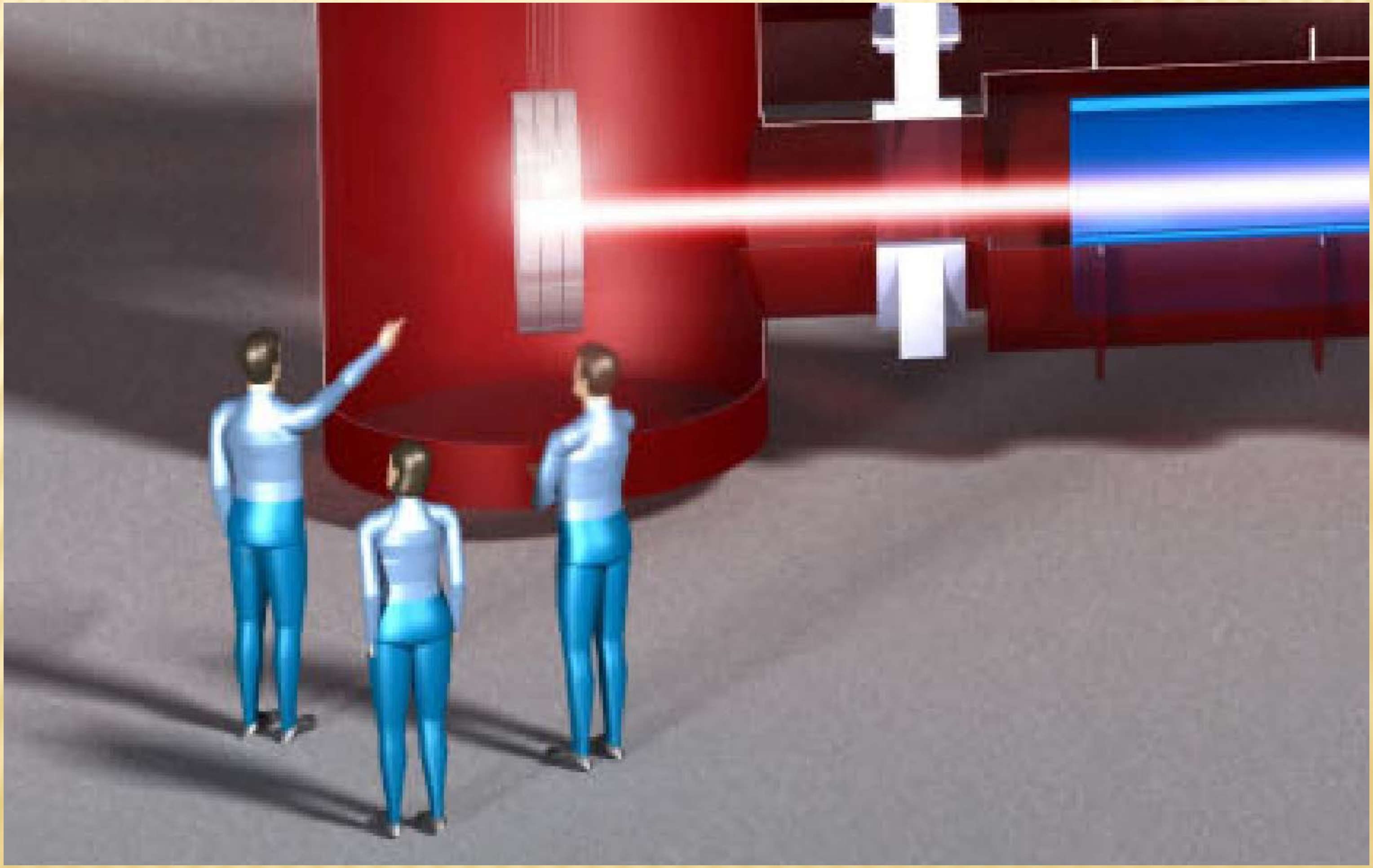


Large hall: *D* = *65* m, *H* = *30* m
Small halls: *D* = *30* m, *H* = *30* m
Lift shaft: *D* = *20* m

SUSPENSIONS



MIRRORS



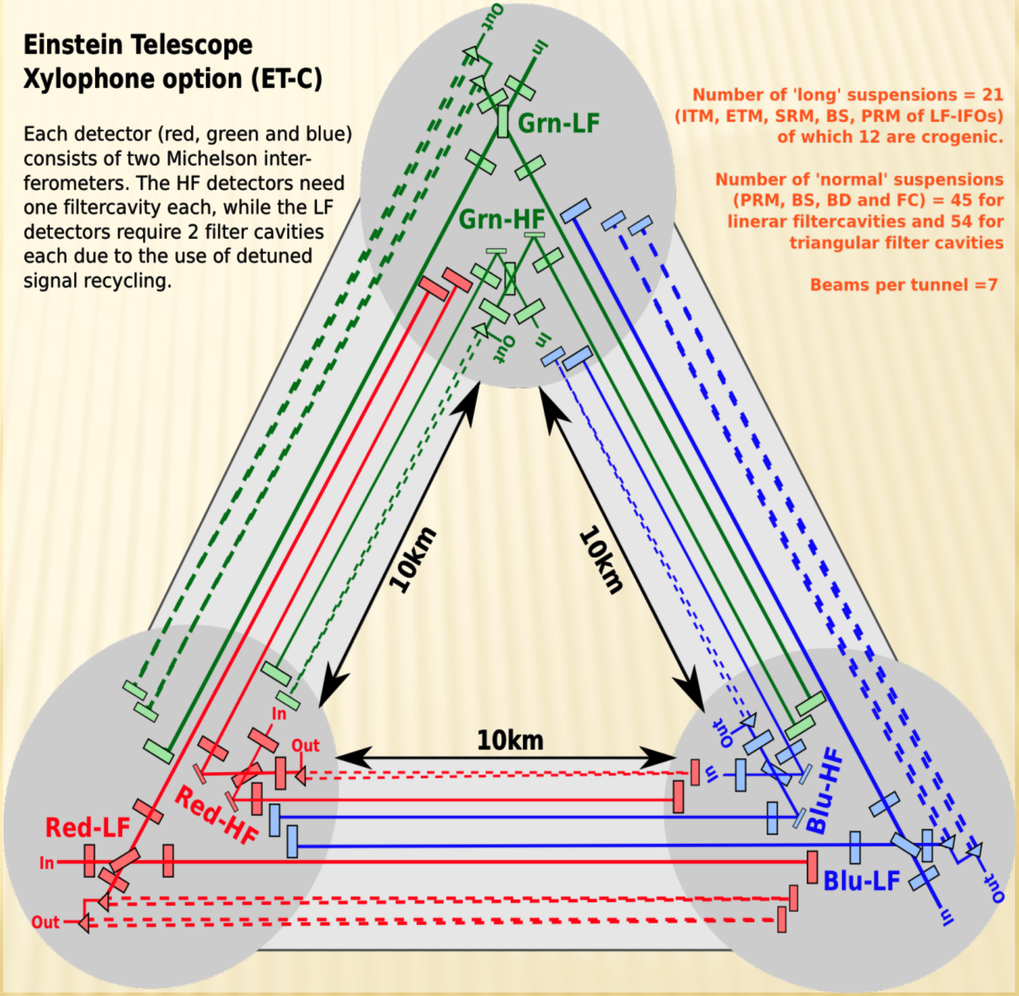
INSTALLATION OF ET

For efficiency reasons build a triangle.

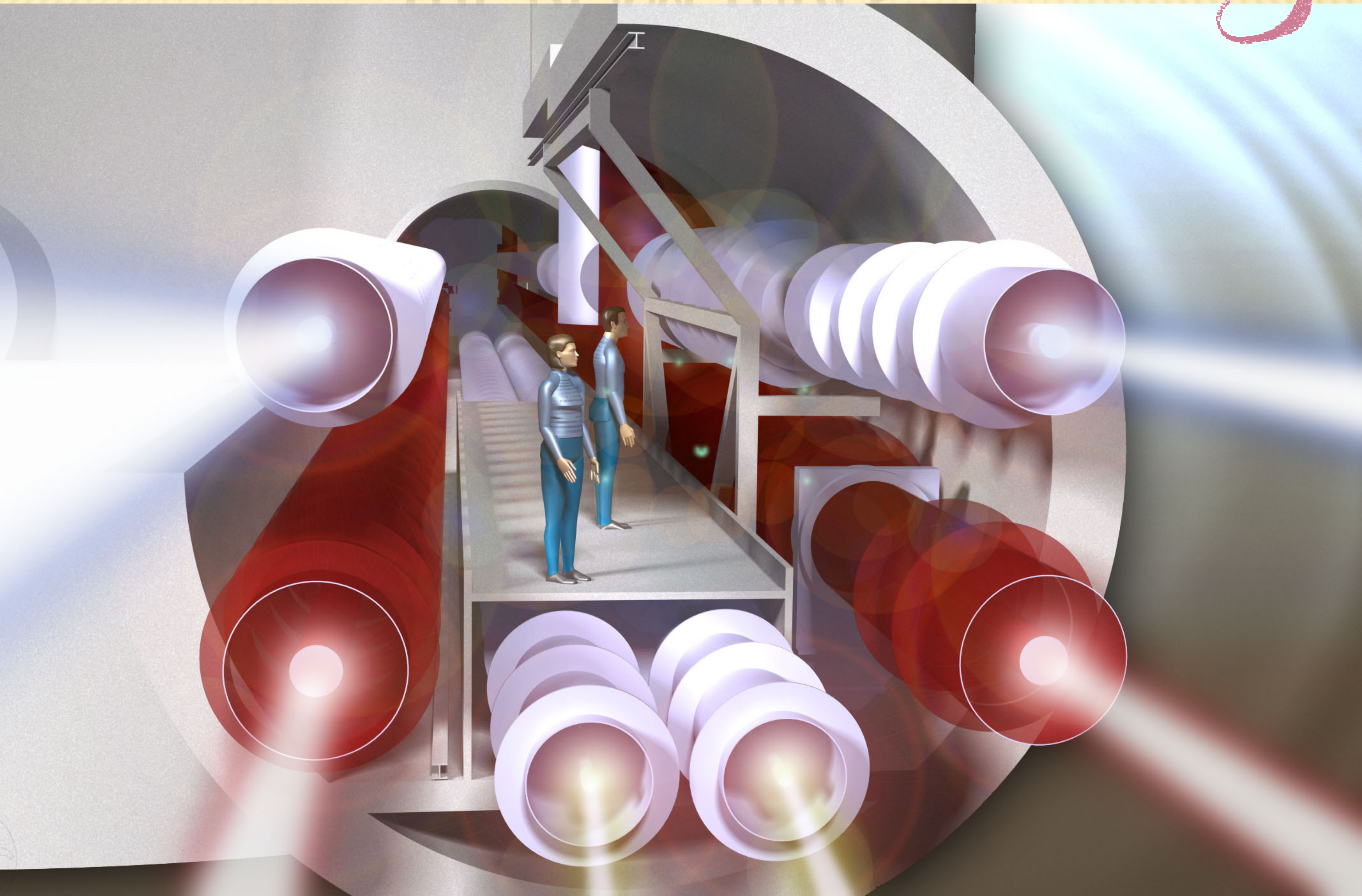
Start with a single xylophone detector.

Add second Xylophone detector to fully resolve polarisation.

Add third Xylophone detector for redundancy and null-streams.



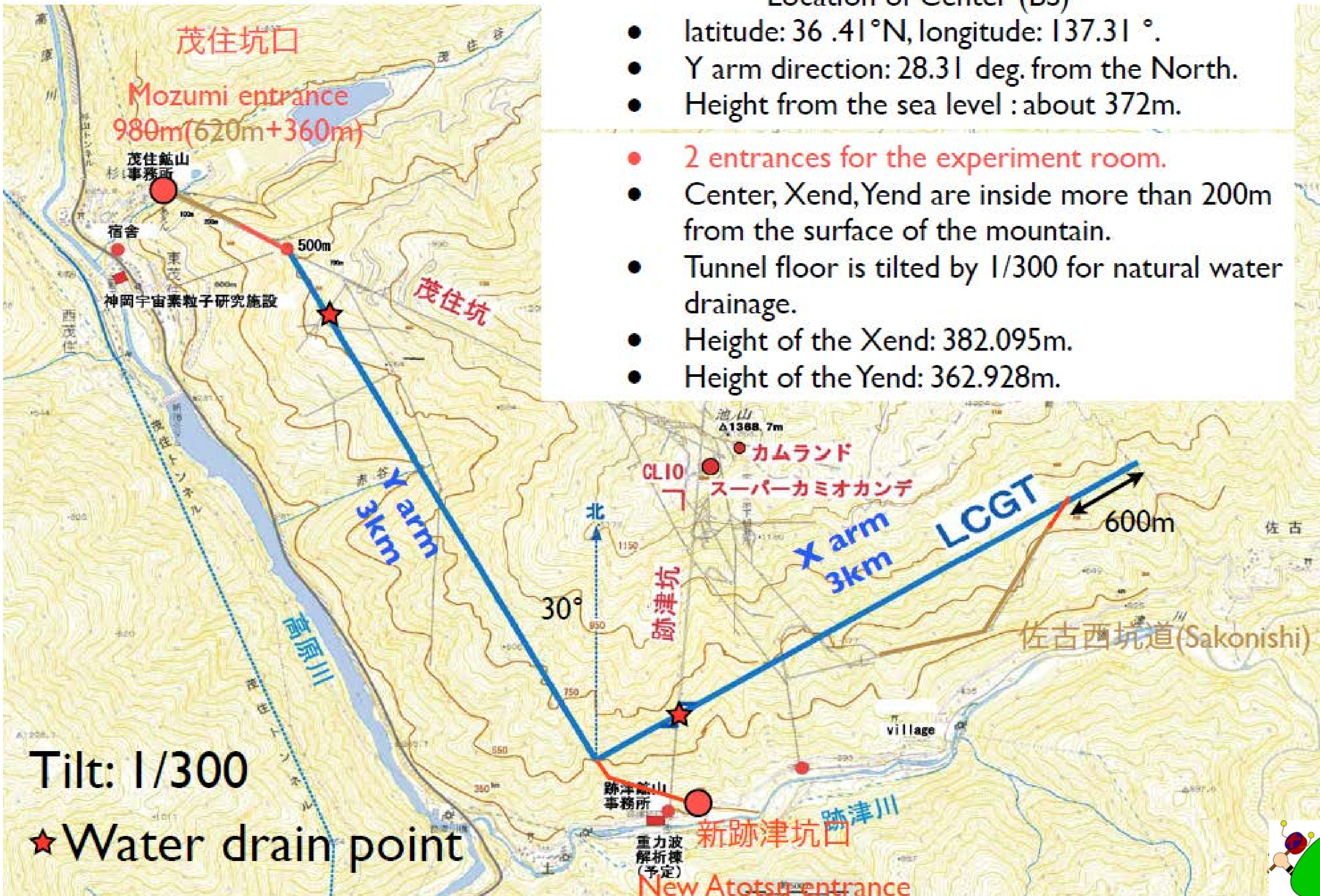
THE BEAM TUBES

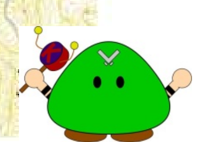


KAGRA

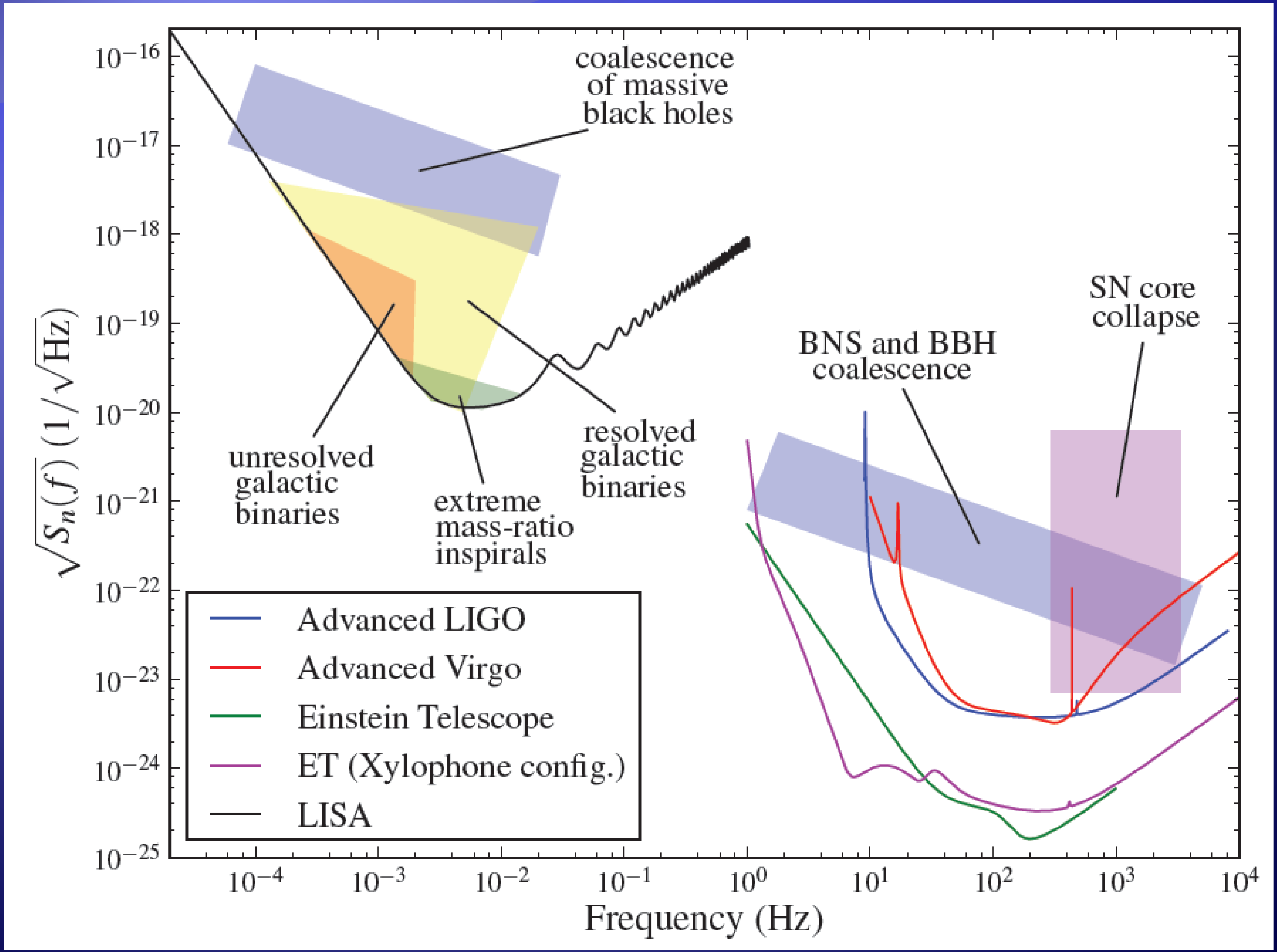
Location of Center (BS)

- latitude: 36 .41°N, longitude: 137.31 °.
- Y arm direction: 28.31 deg. from the North.
- Height from the sea level : about 372m.
- 2 entrances for the experiment room.
- Center, Xend, Yend are inside more than 200m from the surface of the mountain.
- Tunnel floor is tilted by 1/300 for natural water drainage.
- Height of the Xend: 382.095m.
- Height of the Yend: 362.928m.



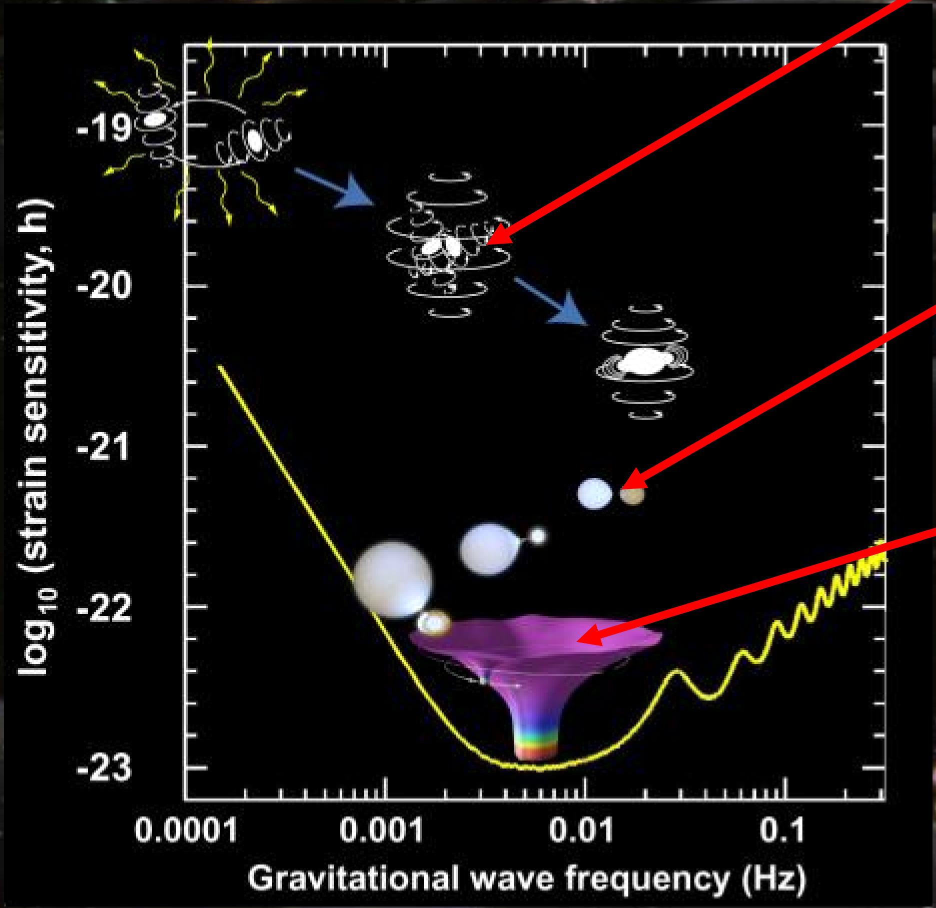


GW sources



coalescence of massive black holes
unresolved galactic binaries
extreme mass-ratio inspirals
resolved galactic binaries
BNS and BBH coalescence
SN core collapse
Advanced LIGO
Advanced Virgo
Einstein Telescope
ET (Xylophone config.)
LISA
$\sqrt{S_n(f)}\ (1/\sqrt{\mathrm{Hz}})$
Frequency (Hz)
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

LISA: A Universe Full of Strong Gravitational Wave Sources

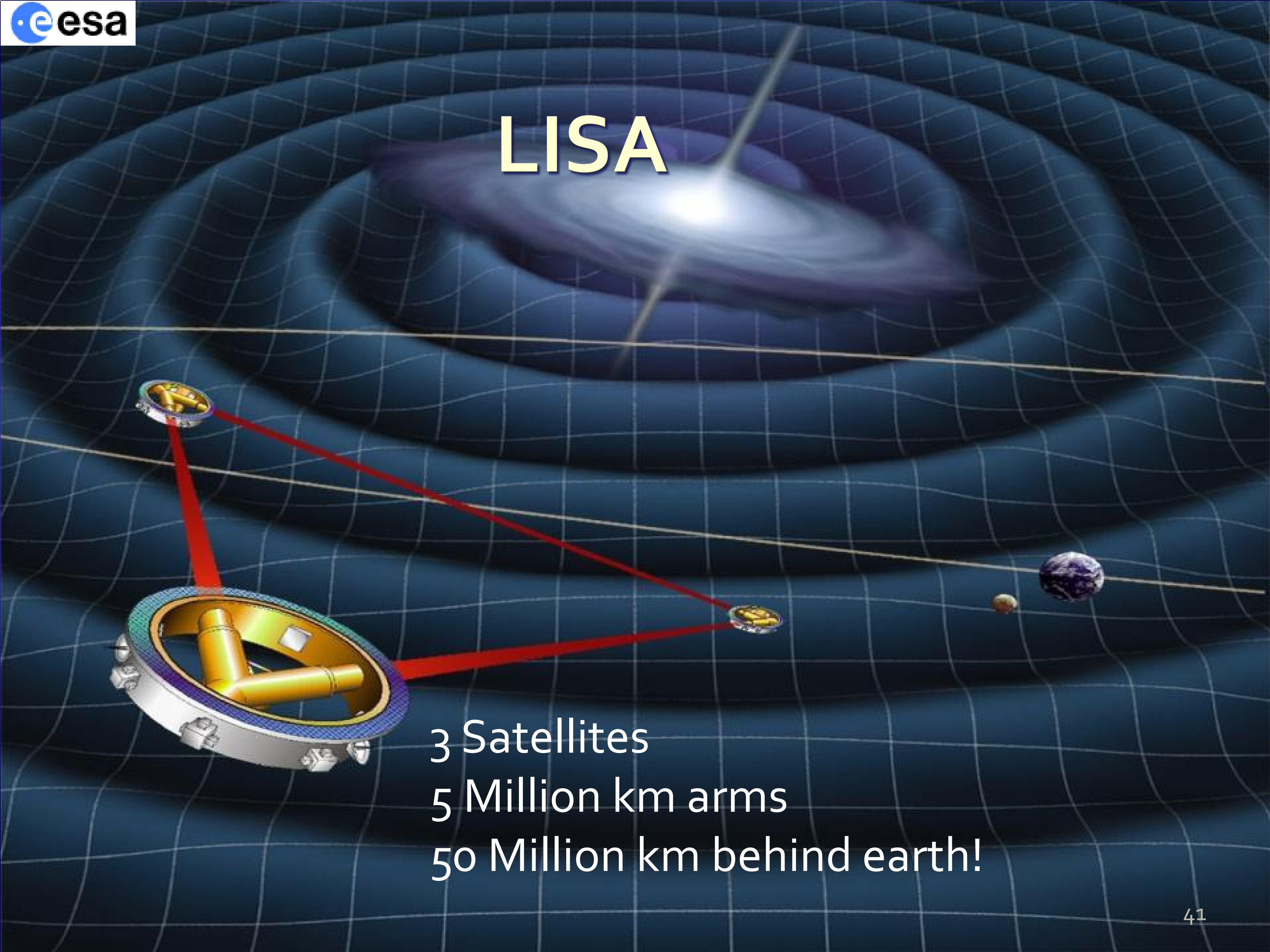


Massive Black Hole Binary (BHB) inspiral and merger (10s-100s)

Ultra-compact binaries (thousands)

Extreme Mass Ratio Inspiral (EMRI) (hundreds)

Cosmic background


esa
LISA
3 Satellites
5 Million km arms
50 Million km behind earth!